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Demonstration of Noncorrosive, Capacitance-Based Water-Treatment Technology for Chilled-Water Cooling Systems

Final Report on Project F09-AR08

Alfred D. Beitelman and Michael K. McNerney

September 2014



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Demonstration of Noncorrosive, Capacitance-Based Water-Treatment Technology for Chilled-Water Cooling Systems

Final Report on Project F09-AR08

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Final report

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Under Project F09-AR08, "High-Voltage Capacitor-Based Water Treatment System for Control of Corrosion, Scale and Biological Growth in Cooling Water Systems"

Abstract

This project demonstrated and validated a high-voltage capacitance-based water-treatment system for chilled-water cooling systems that was previously evaluated in separate work by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). This emerging nonchemical technology, marketed as the Zeta Rod Water Management System, was shown to inhibit mineral scaling and biofouling in chilled-water systems without the need to use hazardous chemicals, including those typically applied to counteract the corrosive effects of conventional treatment chemicals. This project extended the earlier technology evaluation to four military installations with a variety of makeup water qualities and mechanical equipment.

Demonstration results showed that this nonchemical water-treatment system effectively prevents corrosion, scaling, and biofouling in open-loop evaporative cooling towers using a wide range of makeup water chemistries (alkaline to acidic). It also can reduce system water usage by 20% because fewer blowdown cycles are needed to purge impurities, supporting DoD net zero water objectives for installations. A return-on-investment ratio of 3.37 was calculated. The validated applications are recommended for consideration by decision makers to reduce military installation chemical utilization and support Department of Defense Net Zero Water goals.

Contents

Abstract.....	iii
Figures and Tables.....	vi
Preface	viii
Executive Summary	ix
Unit Conversion Factors.....	x
1 Introduction	1
1.1 Problem statement.....	1
1.2 Objective.....	2
1.3 Approach	2
2 Technical Investigation	5
2.1 Technology overview.....	5
2.2 Field work.....	7
2.3 Technology installation and calibration.....	9
2.3.1 Fort Huachuca.....	9
2.3.2 Davis-Monthan AFB	14
2.3.3 Fort Irwin.....	16
2.3.4 Warner Robins AFB.....	20
2.4 System operation and monitoring.....	23
2.4.1 Biofouling monitoring.....	23
2.4.2 Corrosion monitoring	24
2.4.3 Scale monitoring	24
2.4.4 Water analysis procedure.....	24
2.4.5 Water conservation and monitoring.....	25
2.4.6 Other tasks	25
3 Discussion.....	26
3.1 Metrics.....	26
3.1.1 Biofouling.....	26
3.1.2 Corrosion	26
3.1.3 Scaling.....	27
3.1.4 Water analysis	27
3.2 Results.....	27
3.2.1 Biofouling.....	28
3.2.2 Corrosion	28
3.2.3 Scaling	28
3.2.4 Water conservation	30
3.2.5 Swamp cooler demonstration problems.....	34

3.3	Lessons learned	35
4	Economic Analysis	37
4.1	Costs and assumptions.....	37
4.2	Projected return on investment (ROI).....	41
5	Conclusions and Recommendations	42
5.1	Conclusions.....	42
5.2	Recommendations	43
5.2.1	<i>Applicability</i>	43
5.2.2	<i>Implementation</i>	44
	References.....	45
	Appendix A: Data from Demonstration Sites	47
	Appendix B: Borescope Results	73
	Appendix C: Suggested Implementation Language.....	86
	Report Documentation Page	

Figures and Tables

Figures

Figure 1. Water-management system components developed for wireless remote control.....	6
Figure 2. Example of monitoring screen.....	7
Figure 3. Swamp cooler components and principle of operation.	9
Figure 4. Chillers at Fort Huachuca SCP, showing Zeta Rod components mounted on wall in background.	10
Figure 5. Capacitor rods inserted into 1.5 in. thread-o-let fittings in CWS & CWR lines at Fort Huachuca SCP.	10
Figure 6. Two-inch water meters in makeup water line (left) and blowdown water line (right) at Fort Huachuca SCP.....	11
Figure 7. Water-management system components.	11
Figure 8. Components of Zeta system at Fort Huachuca SCP.....	12
Figure 9. Swamp coolers and Zeta system components in Building 52110.....	13
Figure 10. Swamp coolers in Fort Huachuca, Building 51540.	14
Figure 11. Zeta equipment mounted on evaporative condenser at Davis-Monthan Building 2301, Fitness Center.....	14
Figure 12. Equipment layout Building 2301 Zeta application.....	15
Figure 13. Evaporative condenser tube bundle at Building 2301 (Zeta Rod application) showing section of cleaned tubing between zip ties.....	15
Figure 14. Thread-o-let installed in CWS pipe at Fort Irwin Building 263 (left) and electrodes installed in the CWS and CWR pipes (right).....	16
Figure 15. Components of the water-management system in Fort Irwin Building 263.	17
Figure 16. Fort Irwin Building 263 (control) monitoring components.	18
Figure 17. Fort Irwin Building 873 application installed on the 3 in. main water line (left), and with controller/data-logger and wireless communications hardware (right).....	19
Figure 18. Fort Irwin Building 873 (Zeta Rod test site): water meter installed on swamp cooler (left); swamp coolers on the roof (right).	19
Figure 19. Mineral accumulation on swamp cooler pads (left) and cooler frames (right) at startup at Fort Irwin Building 873 Zeta application.	20
Figure 20. Capacitor rods are mounted on 1.5 in. thread-o-let fitting in CWR and CWS lines at Warner Robins chiller #2.	21
Figure 21. Three-inch water meter in makeup water line for cooling tower 2.	21
Figure 22. Water-management system components.	22

Tables

Table 1. Demonstration site summary.....	3
Table 2. Equipment description and operating conditions for each site.....	23
Table 3. Corrosion rates, mils per year (adapted from ASTM MNL20-2ND).....	26
Table 4. Water cost (\$/1,000 gal).	38
Table 5. Estimated annual water use (x 1,000 gal).	39
Table 6. Estimated annual water cost.....	39
Table 7. Estimated annual chemical costs.	40
Table 8. ROI calculation.	41

Preface

This investigation was performed for the Office of the Secretary of Defense under the Department of Defense Corrosion Prevention and Control Program, Project F09-AR08, “High Voltage Capacitor-based Water Treatment System for Control of Corrosion, Scale and Biological Growth in Cooling Water Systems”. The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM) and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire [OUSD(AT&L)], Bernie Rodriguez (IMPW-FM), and Valerie D. Hines (DAIM-ODF).

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), Construction Engineering Research Laboratory – Engineer Research and Development Center (ERDC-CERL). The ERDC-CERL Project Managers were Michael K. McNerney and Alfred D. Beitelman (CEERD-CF-M). A portion of this work was performed by, or under the supervision of, Mandaree Enterprise Corporation, Warner Robins, GA. At the time this report was prepared, Vicki L. Van Blaricum was Chief, CEERD-CF-M; L. Michael Golish was Chief, CEERD-CF; and Kurt Kinnevan, CEERD-CV-T, was the Acting Technical Director for Adaptive and Resilient Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti, and the Director was Dr. Ilker Adiguzel.

The Commander of ERDC was COL Jeffrey R. Eckstein and the Director was Dr. Jeffery P. Holland.

Executive Summary

This report reviews the data collected during a 24 month demonstration/validation project in which the nonchemical, capacitance-based Zeta Rod Water Management System was evaluated for its ability to deliver documented water conservation results while providing corrosion, scaling, and biofouling protection in open-loop evaporative cooling systems. The test sites were at four military installations in Arizona, California, and Georgia, and included systems where the technology was installed as part of a 2010 evaluation.

Results and observations indicated that the technology delivered an average of 20% reduction in makeup water usage and 50% reduction in blowdown while meeting or exceeding criteria for protection of equipment from scale, corrosion, and biofouling. The reduction in makeup water represents a major water savings for an installation, while the reduction of blowdown water represents a significant reduction on the load on an installation's wastewater treatment system. (The direct use of the blowdown water for greywater purposes appears feasible, but was not demonstrated.) The technology was effective in water treatment and deposit control for a wide range of water conditions, from very soft, corrosion-promoting water to very hard, scale-promoting water.

The remote data access and alarm communications feature of the water management technology effectively identified maintenance issues early, and it illustrated the advantage of an always-on remote oversight and control capability.

Results for a small number of swamp coolers that were incidentally included in this demonstration/validation project were inconclusive due to problems described in the text. However, the usable data that were produced support further evaluation of swamp cooler application.

The 30-year return on investment ratio for this technology was calculated to be 3.37. The validated applications are recommended for consideration by decision makers to reduce military installation chemical utilization and support Department of Defense net zero water goals.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	$(F-32)/1.8$	degrees Celsius
British thermal units (International Table)	1,055.056	joules
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
mils	0.0254	millimeters
refrigeration ton	12,000	British thermal units
square feet	0.09290304	square meters

1 Introduction

1.1 Problem statement

Chiller systems are significant consumers of energy, water, and financial resources at military installations in warm climates. Cooling towers are vulnerable to scale formation and bio-fouling, which can reduce operating efficiency. Chemicals used to control scale and biological growth can promote corrosion of chiller system components, which in turn, requires the use of more chemicals to control the corrosion. Balancing these chemical treatments can be difficult. In addition to system-maintenance issues, the treatment chemicals are usually hazardous, so the transport, storage, and use of them involves various risk. Also, chemically treated water must be purged from chiller systems on a prescribed schedule, and this accounts for a high percentage of water use (i.e., waste) at the installation scale.

Military installations also are subject to Federal agency-level requirements for reducing the use of toxic or hazardous chemicals and the consumption of water. Agency goals established in Executive Order (EO) 13423 (2007) include reduction of water use relative to the agency's use in Fiscal Year 2007 by 16 percent at the close of FY 2015. EO 13423 also requires a reduction in the quantity of toxic and hazardous chemicals used and needing disposal. EO 13514 (2009) sets the water-use reduction goal to 26% by FY 2020 (compared with baseline FY 2007), and specifically addresses the efficiency of cooling towers.

To address these water-conservation mandates and the requirements of effective chiller system corrosion control, the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) performed a demonstration/validation (dem/val) of an emerging nonchemical water-treatment technology under the Department of Defense Corrosion Prevention and Control (CPC) Program. The technology, called the Zeta Rod* Water-Management System, is an electrical, capacitance-based water-treatment system developed to control scaling and biofouling in building chiller systems without promoting cor-

* Zeta Rod® is a registered trademark of Zeta Corporation, Tucson, AZ, <http://zetarod.com/about-zeta/>. Zeta Rod systems are protected by U.S. Patent No. 5,591,317, with other U.S. and international trademarks and process patents granted or pending.

rosion. Because Zeta water treatment technology does not require the application of chemical treatments to suppress corrosion, scale, or biofouling, cooling system water does not need to be flushed as often as chemically treated water. Therefore, much less water is wasted during each maintenance cycle, and the discharged water is nonhazardous.

Previously, ERDC-CERL had directed a dem/val project, under Cooperative Research and Development Agreement CRADA-07-CERL-04, with Zeta Corporation. That project was a 16 month, side-by-side comparative study of the technology against a standard chemical treatment program that was performing at the expected level of efficiency. At that time, the equipment was installed in two locations sharing a single source of water, but applied to chillers with significantly different capacities. The results were published in ERDC/CERL TR-09-20 (Beitelman 2009). Because this equipment was still in place and operational when this CPC project began, it was incorporated into the CPC demonstration to provide data on the technology's longer-term performance.

1.2 Objective

The objective of this study was to demonstrate and validate the Zeta Rod water treatment and management system as a method to control scale, biological growth, and corrosion across a range of equipment types and operating conditions. The potential for water-use reduction associated with the demonstration technology were also to be evaluated.

1.3 Approach

Large evaporative cooling systems (chiller/cooling tower type systems) were evaluated at locations representing a range of makeup water quality, from very hard to very soft. Smaller evaporative coolers, commonly called *swamp coolers*, were also included in this study.

Table 1 identifies the four military installations serving as demonstration sites, and indicates the Zeta Rod application, the control application, the buildings where the cooling equipment was located, and types of cooling systems. The table includes the two Zeta Rod systems that were installed under a previous ERDC-CERL project and further monitored under this project.

Table 1. Demonstration site summary.

Site	Treatment Type	Location	Equipment type
Fort Huachuca, AZ	Zeta Rod*	Building 62601 – South Central Plant (SCP) cooling tower	Two 1,600 kWh (450 RT†) centrifugal chillers.
	Control: Chemical Treatment	Building 81504 – North Central Plant (NCP) cooling tower	Two 1,600 kWh (450 RT) centrifugal chillers.
	Zeta Rod	Building 52110	Evaporative swamp coolers
	Control: No Treatment	Building 51540	Evaporative swamp coolers
Davis-Monthan Air Force Base, AZ	Zeta Rod*	Building 2301 - Fitness Center	425 kWh (120 RT) Evaporative Condenser
	Control: Chemical Treatment	Building 1610	385 kWh (110 RT) Evaporative Condenser
Fort Irwin, CA	Zeta Rod	Building 263 – Cooling tower	One 1,230 kWh (350 RT) centrifugal chiller
	Control Chemical Treatment	Building 273 – Cooling tower	One 1,230 kWh (350 RT) centrifugal chiller
	Zeta Rod	Building 873 –	Evaporative swamp cooler
	Control: No Treatment	Building 879	Evaporative swamp cooler
Warner Robins Air Force Base, GA	Zeta Rod	Building 177 –Chiller/Cooling Tower #2	5,255 kWh (1,500 RT) centrifugal chiller
	Control: Chemical Treatment	Building 177 –Chiller/Cooling Tower #4	5,255 kWh (1,500 RT) centrifugal chiller

* The Zeta Rod systems in these buildings were installed under CRADA-07-CERL-04.

† RT means refrigeration ton, a unit of measure for cooling systems.

Four open-loop cooling systems (one at each site) were equipped with the demonstrated technology as the only water treatment. Four similar systems were operated as controls, using conventional chemical water treatment. Scale, corrosion, biofouling, and water consumption were monitored and compared at each site to evaluate water efficiency.

The demonstrated technology was also applied to swamp cooler systems in two buildings at Fort Irwin and two at Fort Huachuca. The demonstrated system was installed in the main water line serving one building at each installation. Meters were installed in selected swamp coolers to monitor the amount of water used. New cooler pads* were weighed, installed in the test coolers, and left in place for 2–3 months. At the end of this service period, the pads were removed, dried, and reweighed. The purpose of this task was to measure the weight gain per volume of water consumed by the

* These serve as wicks for the evaporation of system water to transfer heat out of the system.

cooler to determine if the pads in the coolers treated with the demonstrated technology would accumulate less mineral residue.

2 Technical Investigation

2.1 Technology overview

Theory developed in the 1940s has suggested that strong electrostatic dispersion of colloidal particles can be achieved by forming a capacitor within a hydraulic system. Inserting an insulated electrode into a grounded pipe or vessel containing water and energizing with high-voltage direct current creates a strong electrostatic field and corresponding capacitance. The development and application of a nonchemical water-treatment technology that is based on this phenomenon has been expansively described and documented (Pitts 1995; Pitts 1997; Romo and Pitts 1999, 2000; Romo, Pitts, and Hector 2002; Romo, Pitts, and Handagama 2007).

When direct current is applied through the electrode, a large voltage potential is created between the two plates of the capacitor (i.e., the electrode and the grounded steel of the hydraulic system). The electrostatic field in the system reduces water surface tension and boosts the surface charges of colloidal particles and wetted surfaces. This effect mineral species and microbes from agglomerating on surfaces or adhering to each other, instead keeping them in suspension. (It also suppresses the bacteria count in the water.) Because the formation of deposits is inhibited, a chilled-water cooling system can be operated at higher cycles of concentration when this technology is applied. An additional beneficial effect is that the cooling tower water takes on noncorrosive characteristics, as indicated by a positive Langelier Saturation Index (LSI). This means that it is not necessary either to use chemical treatments to inhibit mineral scale or the required counter-treatments to simultaneously inhibit corrosion.

The scope of the work documented in the earlier CRADA dem/val of this technology (Beitelman 2009), which was referred to in section 1.1, was limited to a side-by-side comparison of the Zeta Rod with a standard chemical water-treatment program. The demonstrations took place in similar open-loop cooling systems of different capacities at two military installations located in the southwestern United States: Fort Huachuca and Davis-Monthan Air Force Base (AFB), AZ. Feed water quality at both facilities was similar, and allowed for operation of the nonchemically treated cooling systems at high cycles of concentration under conditions that would normally be favorable to scaling, but because of the incoming water

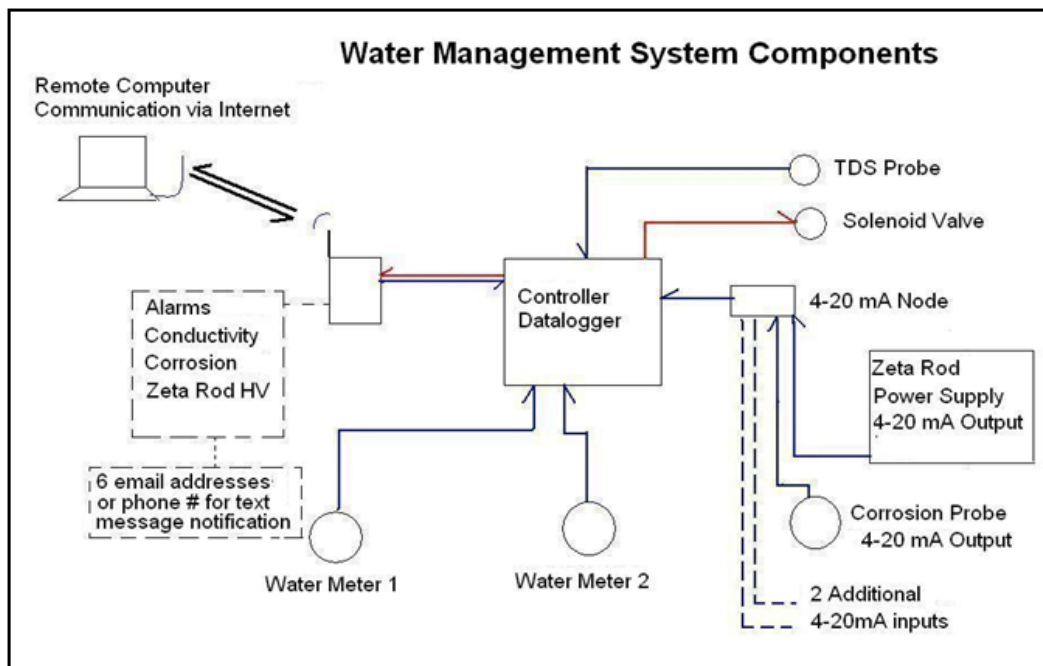
quality, unfavorable to corrosion. The results obtained during the CRADA dem/val were positive, but the work covered only a narrow range of water chemistry. The initial successful results justified an expanded dem/val under the CPC Program to evaluate the technology's ability to perform under a wide range of water chemistries and different operating conditions.

In this project, the water-management system used at each cooling tower consisted of the following components for web-enabled wireless tracking of cooling tower status:

- data logger/controller
- treatment system power supply with alarm signal generator
- volumetric ratio bleed controller
- electronic corrosion probe and signal transmitter
- wireless router and cellular communications hardware (or hard data line)
- conductivity control capability.

Figure 1 shows the system inputs and outputs.

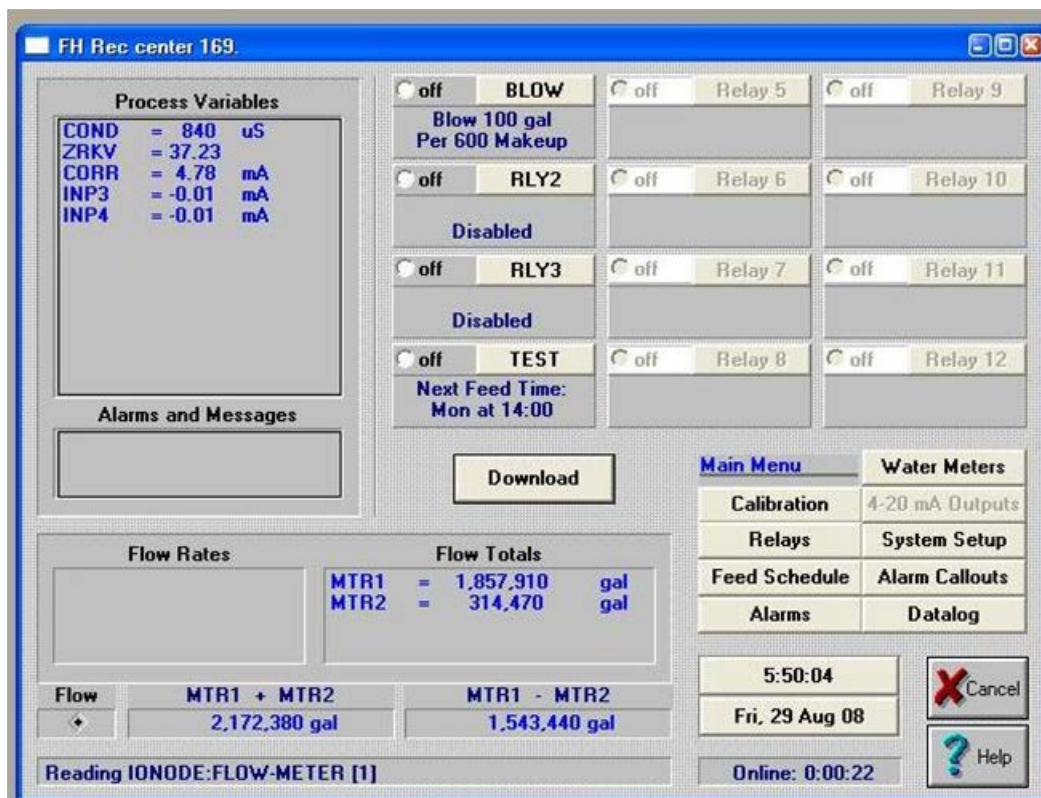
Figure 1. Water-management system components developed for wireless remote control.



Real-time monitoring was accomplished via web connection to the data controller and software, which allowed system adjustments to be made

remotely. The control and monitoring components were installed at all four evaporative cooler sites, but not on the swamp cooler sites. Monitoring for pH was included at Warner Robins AFB due to the potentially corrosive nature of the feed water. Figure 2 shows the remote monitoring and control screen as displayed by the monitoring software.

Figure 2. Example of monitoring screen.



2.2 Field work

To assess the potential for use of the water treatment technology and wireless monitoring capabilities in evaporative cooling equipment, "side by side" cooling tower systems of similar capacity and use were selected at Fort Huachuca, Fort Irwin, and Warner Robins AFB. Evaporative condensers of similar capacity and use were selected at Davis-Monthan AFB.

Of the cooling towers at each site, one continued to operate under a conventional chemical-treatment program and the other was equipped with Zeta Rod technology. While monitoring and control equipment was installed in all locations, the controls were used only on the towers equipped with the demonstration technology. The chemically treated towers (i.e., control sites) used the monitoring equipment only for remote data logging;

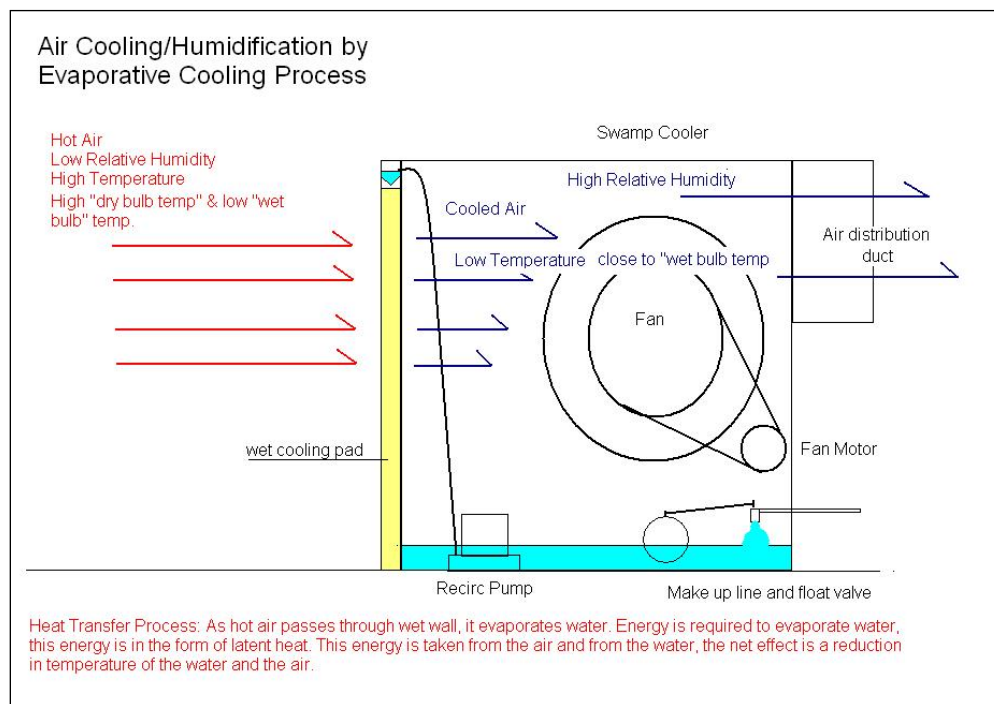
blowdown to the cooling tower remained under the control of the facility's maintenance personnel or chemical service provider.

Corrosion coupons were installed at all four sites to match the metallurgy of the equipment. The coupons were replaced at 90 day intervals and sent to a certified laboratory for weight-loss analysis. Monthly water samples were collected at all sites and sent to certified labs for mineral, metal and bacteriological analyses.

Borescope inspections were performed in February 2010, January 2011, and November/December 2011. Each of the four sites was also equipped with an electronic corrosion monitoring probe and transmitter.

For the swamp cooler applications, two buildings at Fort Huachuca and two at Fort Irwin, each with similar evaporative coolers were selected. (Figure 4 shows a basic schematic drawing of a typical swamp cooler, including the cooling pad that was weighed as part of Zeta Rod performance evaluation.) The demonstration technology was installed on one building at each base on the main water line feeding the entire building. Selected cooling units on each roof were equipped with preweighed cooling pads. The pads were removed on 60–90 day intervals, then dried and reweighed. The coolers were also equipped with water meters to monitor water consumption, and they were photographed to document mineral accumulation.

Figure 3. Swamp cooler components and principle of operation.



2.3 Technology installation and calibration

2.3.1 Fort Huachuca

2.3.1.1 South Central Plant (SCP) Zeta Rod application

Four model ZR36S Zeta Rods and one model ZRPGM 35 kV direct current (DC) power supply was installed as the water treatment for the cooling tower and chillers at the SCP (Figure 4). The systems were installed in the condenser water supply (CWS) and the condenser water return (CWR) piping of each condenser. To install the capacitor rods, 1.5 in. mild steel thread-o-lets* were welded into a pipe elbow. Figure 5 shows the thread-o-lets with the rods installed into the piping.

* A thread-o-let is a threaded external pipe fitting that is welded to a hole in a pipe wall to create a new branch connection.

Figure 4. Chillers at Fort Huachuca SCP, showing Zeta Rod components mounted on wall in background.



Figure 5. Capacitor rods inserted into 1.5 in. thread-o-let fittings in CWS & CWR lines at Fort Huachuca SCP.



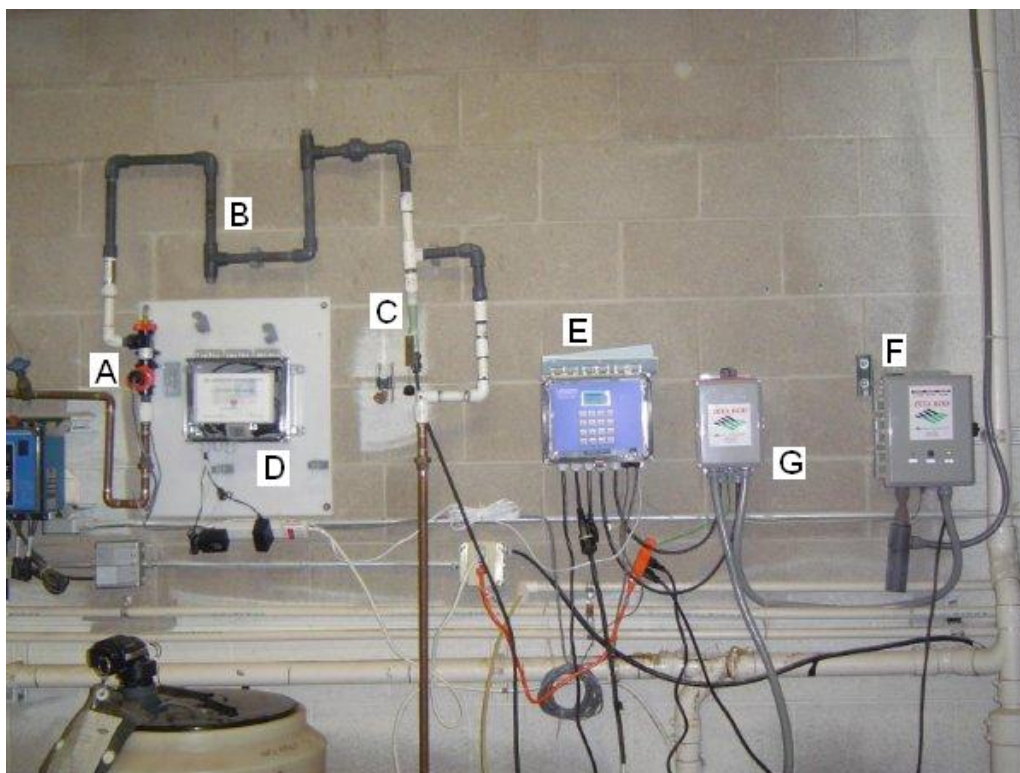
Conventional plumbing practices were used for the installation of the 2 in. water meters. Figure 6 indicates the water meters on the makeup (MU) water line and blowdown (BD) water line respectively.

Figure 6. Two-inch water meters in makeup water line (left) and blowdown water line (right) at Fort Huachuca SCP.



Figure 7 shows all the hardware used in the water-management system.

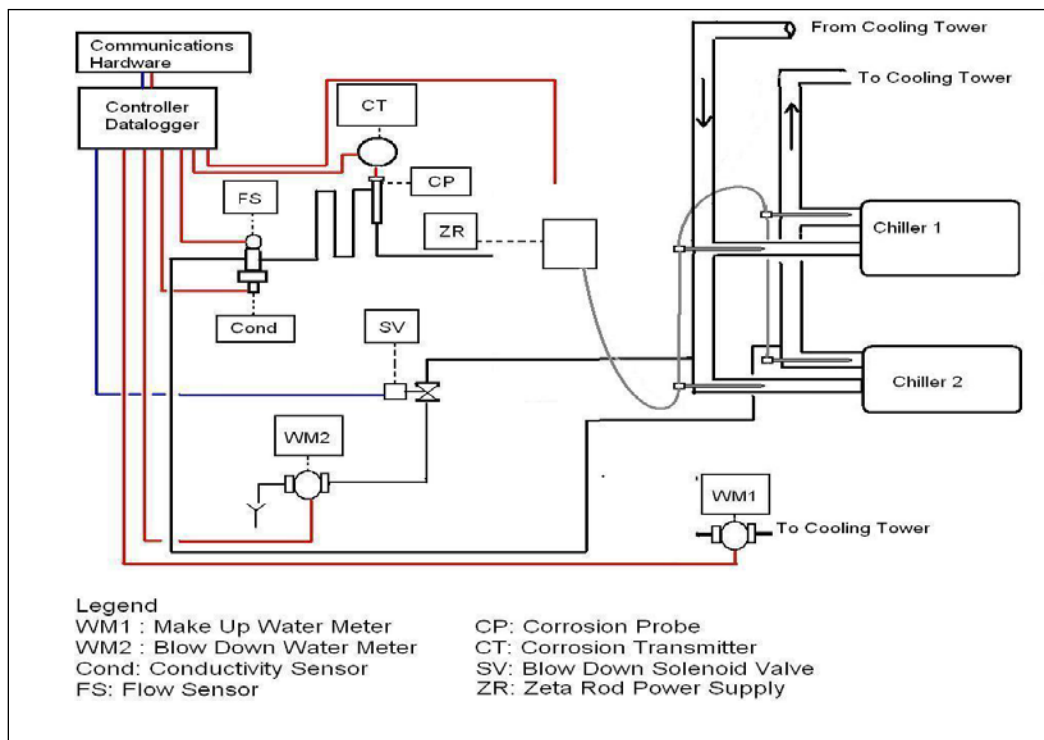
Figure 7. Water-management system components.



Reading from Figure 7, the components are (A) conductivity sensor and flow switch plumbing assembly; (B) pressure flow regulator and corrosion coupon rack; (C) electronic corrosion probe; (D) wireless communications hardware; (E) controller/data logger; (F) power supply for capacitor; and (G) enclosure for corrosion probe transmitter power supply (transmitter not shown).

Figure 8 shows the components of the demonstrated water-treatment system installed at the South Central Plant.

Figure 8. Components of Zeta system at Fort Huachuca SCP.



The volumetric ratio cycle control was programmed at 400 gallons of blowdown for every 2,000 gallons of makeup ($2,000/400 = 5$ cycles of concentration).

2.3.1.2 North Central Plant (NCP) control site

Identical monitoring instrumentation was installed at the NCP. Since this was a control location, no welding was required. The existing conductivity controller was left in place and operated under the existing settings. This controller continued to control the blowdown solenoid valve for the cooling tower at this location. The monitoring instrumentation collected data from the conductivity probe, the corrosion probe and the two water meters. Calibration checks of all instrumentation were performed prior to the installation of the system.

2.3.1.3 Building 52110 swamp cooler Zeta Rod application

A capacitance-based treatment system consisting of a ZR18S Zeta Rod, ZR200S stainless steel chamber and ZRPGM power supply were installed

into the 2 in. main water line feeding the building. A controller/data-logger was installed in the room and set to continuously monitor the high voltage (HV) output of the power supply through a 4 – 20 milliamp (mA) circuit and programmed to send an alarm if the signal dropped below 10 mA. Figure 9 shows the Zeta system installed in the main water line feeding the building as well as one of the swamp coolers mounted on the roof of the building.

Figure 9. Swamp coolers and Zeta system components in Building 52110.



A 0.5 in. water meter was installed in one of the swamp coolers on the roof of the building to begin water consumption data collection. Due to the distance between the cooler and the location of the data-logger it was not possible to connect the water meter to the controller. However, the meter was equipped with a totalizer counter and was read and recorded during the monthly visits to the facility.

Each of the coolers on this building had three pads measuring 45.5 x 33.5 in. One preweighed pad was installed in the test cooler for each test.

2.3.1.4 Building 51540 swamp cooler control site

Work at this building consisted of installing a 0.5 in. water meter on the feed line to one of the two swamp coolers on the side of the building. Each of the coolers at this building had six 44.5 x 21.5 in. pads and one preweighed pad was installed in the test cooler during each test. Figure 10 shows the swamp coolers on the side of the building.

Figure 10. Swamp coolers in Fort Huachuca, Building 51540.



2.3.2 Davis-Monthan AFB

2.3.2.1 Building 2301 Zeta Rod application

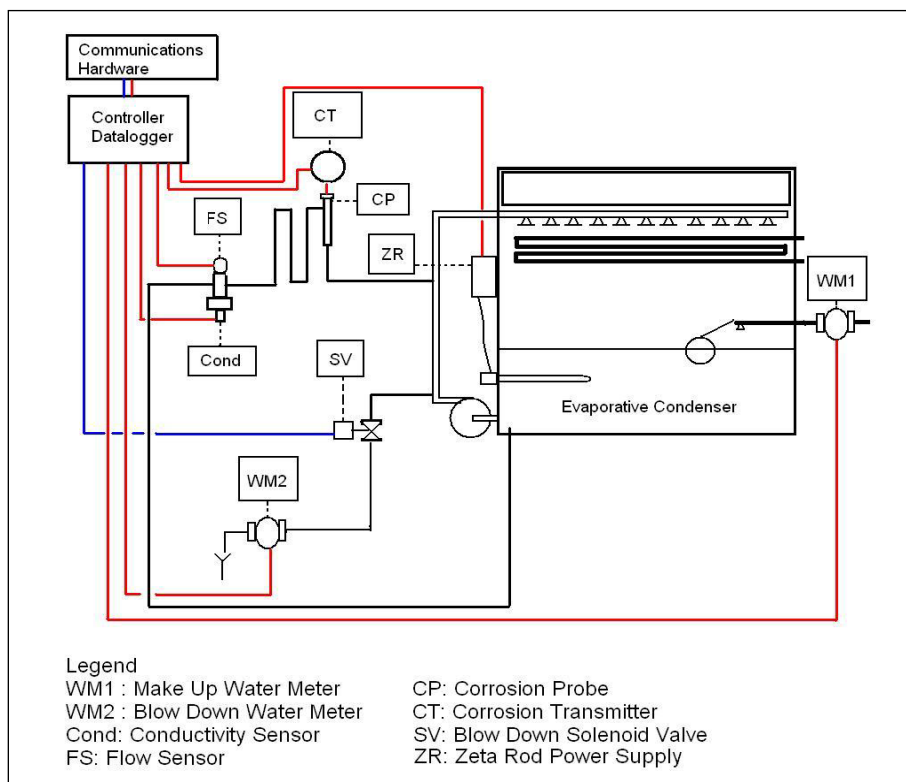
The equipment at this location, installed for the 2007 CRADA dem/val (Figure 11) was inspected for proper operation and for calibration.

Figure 11. Zeta equipment mounted on evaporative condenser at Davis-Monthan Building 2301, Fitness Center.



Figure 12 shows the layout of the equipment installed at this location.

Figure 12. Equipment layout Building 2301 Zeta application.



The condenser tubes were photographed to record their condition. One tube had been previously cleaned and tagged with zip-ties to serve as a coupon to evaluate the formation of new deposits (Figure 13).

Figure 13. Evaporative condenser tube bundle at Building 2301 (Zeta Rod application) showing section of cleaned tubing between zip ties.



On 17 August 2009 the controller was set to a volumetric ratio of 400:100, or 100 gallons of blowdown for every 400 gallons of makeup.

2.3.2.2 Building 1610 control site

Equipment installed on the control site consisted of a controller/data-logger, corrosion coupon rack, electronic corrosion probe and transmitter, makeup and blowdown water meters, and a wireless communications hardware system. No changes were made to the existing blowdown control as installed by the chemical contractor for the facility.

2.3.3 Fort Irwin

2.3.3.1 Building 263 Zeta Rod application

Two model ZR36S Zeta Rods and one model ZRPGM power supply was installed as the treatment for the cooling tower and chiller. The capacitor rods were installed, one each into the condenser water supply (CWS) and condenser water return (CWR) pipes going in and out of the condenser. Figure 14 shows the thread-o-lets with the Zeta Rods inserted.

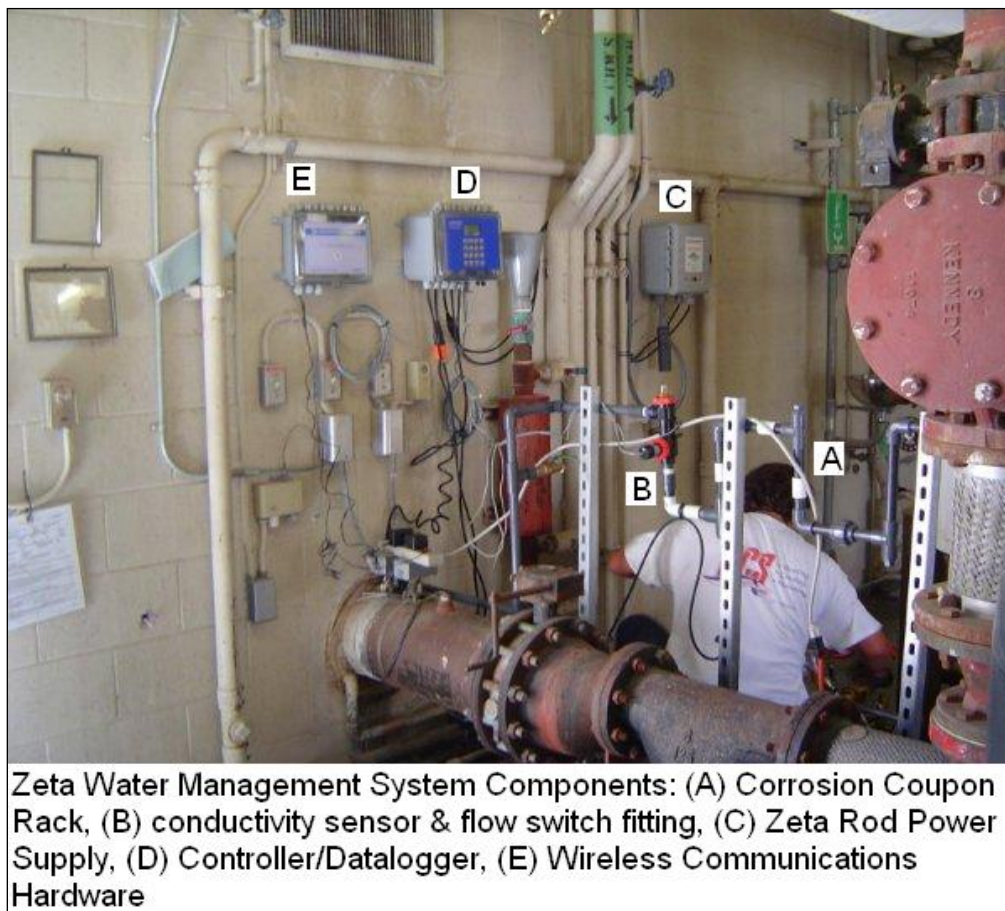
Figure 14. Thread-o-let installed in CWS pipe at Fort Irwin Building 263 (left) and electrodes installed in the CWS and CWR pipes (right).



Conventional plumbing practices were used for the installation of the 2 in. water meter in the makeup line and the 0.75 in. water meter for the blow-down.

Figure 15 shows the components of the water-management system installed at this location.

Figure 15. Components of the water-management system in Fort Irwin Building 263.



On 12 August 2009 the controller was set initially to blowdown by a conductivity set point of 3,000 microsiemens (μS). It was switched to blowdown by volumetric ratio control on August 24, 2009 to allow 300 gallons of blowdown for every 1,500 gallons of makeup ($1,500/300 = 5$ cycles of concentration). It was adjusted to a 1,000/200 ratio on August 25 to reduce variance in the cooling tower conductivity.

2.3.3.2 Building 273 control site

The same monitoring instrumentation was installed at this location as in Building 263 (Figure 16). No Zeta Rods were installed, so no welding was required at this site. The existing conductivity controller was left in place at its existing settings. This controller continued to control the blowdown solenoid valve for the cooling tower at this location. The water-management system collected data from the conductivity probe, the corrosion probe and the two water meters.

Figure 16. Fort Irwin Building 263 (control) monitoring components.



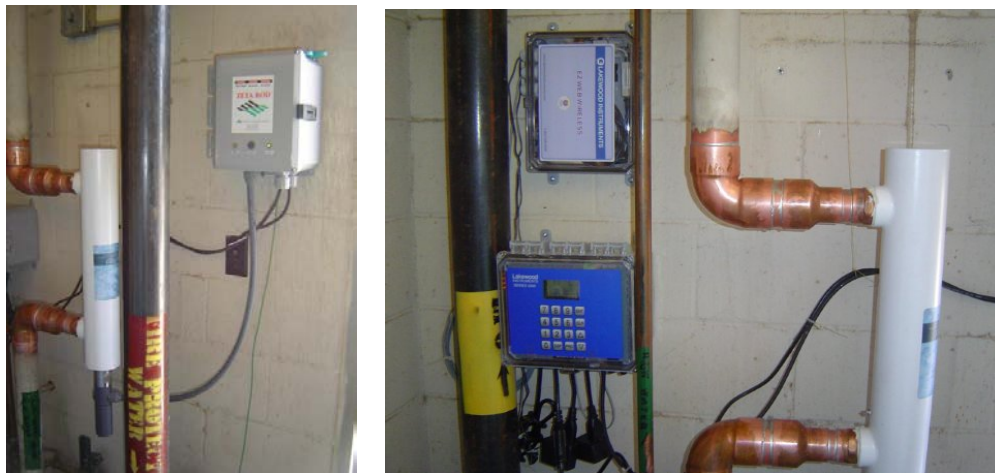
Calibration checks of all existing instrumentation were performed before installation of the monitoring system.

2.3.3.3 Building 873 swamp cooler Zeta Rod application

A Model ZR18S Zeta Rod, a model ZR200S stainless steel chamber, and Model ZRPGM power supply were installed in the 3 in. main water line serving the entire building.

A controller/data logger unit was installed in the mechanical room (Figure 17) and set to continuously monitor the high-voltage output of the power supply through a 4 – 20 mA circuit and programmed to send an alarm if the signal dropped below 10 mA.

Figure 17. Fort Irwin Building 873 application installed on the 3 in. main water line (left), and with controller/data-logger and wireless communications hardware (right).



Three 0.5 in. water meters were installed in three swamp coolers (Figure 18) on the roof of the building to begin water-consumption data collection. The coolers selected for this purpose were at the north and south ends of the building and one at the center of the building.

Figure 18. Fort Irwin Building 873 (Zeta Rod test site): water meter installed on swamp cooler (left); swamp coolers on the roof (right).



Most of the coolers at this location, as shown in Figure 19, had heavy mineral buildup and accumulation both on the pads and the external frame of the units.

Figure 19. Mineral accumulation on swamp cooler pads (left) and cooler frames (right) at startup at Fort Irwin Building 873 Zeta application.



2.3.3.4 Building 879 control site

Work at this building consisted of installing three 0.5 in. water meters on the feed line to three of the swamp coolers on the roof of the building. Coolers in the same respective locations were selected as in Building 873 for the testing and water metering: north end of building, center and south end.

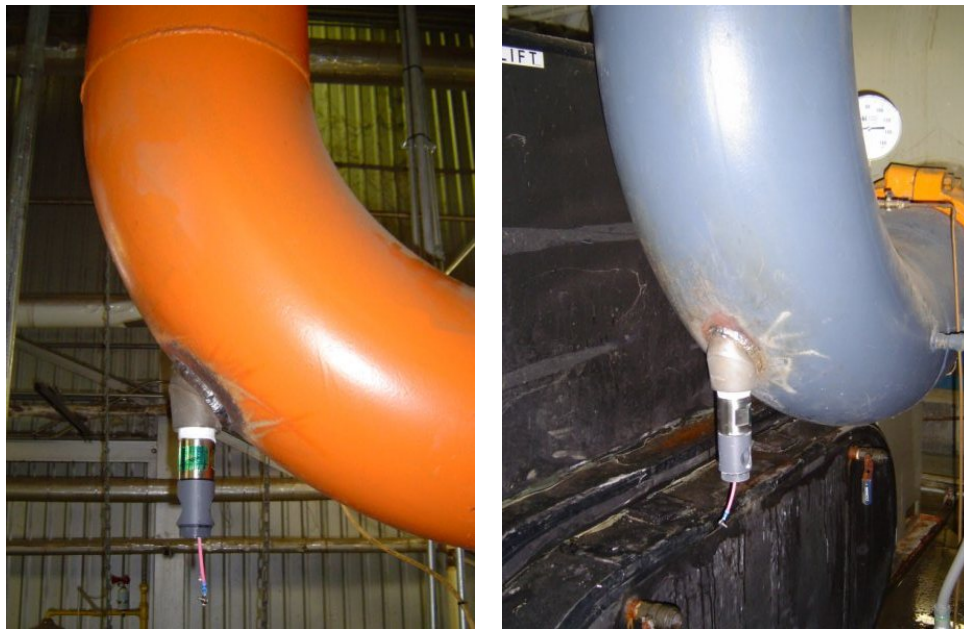
2.3.4 Warner Robins AFB

The two chillers used in the project were located in the same plant. Chiller and cooling tower #2 was selected as the Zeta Rod site, and chiller and tower #4 were used as the control site. The chillers were identical 1,500 refrigeration ton (RT) units.

Two model ZR36S Zeta Rods and a power supply model ZRPGM were installed into cooling tower and chiller #2. The rods were inserted into the CWS and CWR pipes going in and out of the condenser.

To install the capacitor rods it was necessary to weld a 1.5 in. thread-o-let mild steel fitting at elbows in the pipes. Figure 20 shows the thread-o-lets with the capacitor rods inserted into the CWS and CWR pipes to each one of the two chillers in the plant.

Figure 20. Capacitor rods are mounted on 1.5 in. thread-o-let fitting in CWR and CWS lines at Warner Robins chiller #2.



Conventional plumbing practices were used for the installation of the 3 in. makeup water meters and 0.75 in. blowdown water meters. Figure 21 shows the water meter on the makeup water line for cooling tower 2.

Figure 21. Three-inch water meter in makeup water line for cooling tower 2.



Figure 22 shows all the hardware used in the water-management system on chiller 2.

Figure 22. Water-management system components.



Due to the very low conductivity of the water at this location, volumetric ratio cycle control was programmed at 100 gallons of blowdown for every 1,500 gallons of makeup ($1,500/100 = 15$ cycles of concentration).

Table 2 shows a summary of the description of each site and the operating conditions with respect to blowdown for the cooling towers. Test towers were set under a volumetric ratio control (volume of makeup to volume of blowdown) whereas control towers remained under a conductivity set point.

Table 2. Equipment description and operating conditions for each site.

Fort Huachuca	Equipment	Operation (mo/yr)	MU Cond	BD Set point	Cycles of Conc.*
South Central Plant SCP (Capacitor system)	Two 1,494 kW (425 RT) Trane Chillers & 2-Cell Cooling Tower	12	330 uS	500:100 800 uS	5 vol. 2.42 cond.
North Central Plant (Control)	Two 1,494 kW (425 RT) Trane Chillers & 2-Cell Cooling Tower	12	330 uS	900 uS	2.72 cond.
Davis-Monthan AFB					
Bldg 2301 (Capacitor system)	One 386 kW (110RT) Evaporative Condenser	12	350 uS	400:100	4 vol.
Bldg 1610 (Control)	One 386 kW (110RT) Evaporative Condenser	12	350 uS	1,200 uS	3.4 cond.
Fort Irwin					
Bldg 263 (Capacitor system)	One 1,230 kW (350 RT) Chiller & Cooling Tower	6 to 8	960 uS	400:100	4 vol.
Bldg 273 (Control)	One 1,230 kW (350 RT) Chiller & Cooling Tower	6 to 8	960 uS	1,200 uS	1.25 cond.
Warner Robins AFB					
CT#2 (Capacitor system)	One 5,275 kW (1,500RT) Chiller & Cooling Tower	6 to 8	115 uS	1,200:100	12 vol.
CT#4 (Control)	One 5,275 kW (1,500RT) Chiller & Cooling Tower	6 to 8	115 uS	800 uS	7 cond.

2.4 System operation and monitoring

2.4.1 Biofouling monitoring

For this project, dip slides were used to perform total aerobic bacteria counts on a monthly basis. Tests made periodically during operation of the cooling system provided a record of any changes in the bacterial count during any particular season. These tests were also used to determine the effectiveness of a biocide program and to indicate when treatment should be altered.

Opinions differ on acceptable limits of bacteria in a recirculating water system. McCoy (1983) indicates that viable plate counts are seldom obtained for less than 10,000 colony-forming units per milliliter (cfu/ml), even when measured immediately after treatment with biocide, due to the constant inoculation of the system. Counts of 100,000 – 500,000 cfu/ml

indicate a biologically clean system, and when counts exceed 600,000 for an extended period, a biocide treatment is warranted.

2.4.2 Corrosion monitoring

The most common method of monitoring for corrosion is by inserting test coupons into the cooling water loop, which is described in ASTM D2688, *Corrosivity Testing of Industrial Cooling Water (Coupon Test Method)*.

In addition to standard corrosion coupons, electrical resistance corrosion probes* with mild steel elements were installed at each site. The purpose of using the probes was to be able to detect a potential increase in corrosion rates without having to wait the required 90 day exposure period of the coupons.

2.4.3 Scale monitoring

Borescope inspections of the tubes in the condensers were scheduled at different intervals to evaluate the conditions of the tubes and determine the presence of any scale deposits and or other changes. Condenser tube bundles were visually marked and inspected for scale formation.

Swamp coolers were monitored and documented photographically. Preweighed cooler pads were installed and removed at 60 – 90 day intervals to measure the weight gain at the treated versus the untreated sites.

2.4.4 Water analysis procedure

Water samples were sent to independent labs† for analyses. Warner Robins required a second makeup water sample to be analyzed in March of 2010 when the base switched the source of their makeup water. Information about all water-analysis metrics is presented in section 3.1.4.

* Probes utilized were ER327E0031137500. Adjustable length E/R probe with 40-mil, epoxy sealed, wire loop element in carbon steel/copper on 3/4-in. MNPT nylon fitting. Transmitters: IN2500E. 4 – 20mA Single Channel ER Transmitter Instrument. Manufacturer: Metal Samples Co., Inc., Mumford, AL.

† Fort Huachuca, Davis-Monthan and Fort Irwin: Turner Laboratories, Tucson, AZ:
<http://www.turnerlabs.com>. Warner Robins: Summit Environmental Technologies Inc., Cuyahoga Falls, OH: <http://www.settek.com>.

During the monthly visits, dip slides* were also collected at all four sites and analyzed for total bacteria, yeast, and mold.

2.4.5 Water conservation and monitoring

The term *cycles of concentration* refers concentration level of minerals in system recirculating water. As water evaporates from a cooling tower, the concentration of minerals increases. High levels of dissolved minerals in a cooling system promotes scaling.

Water is conserved when a tower is operated at higher cycles of concentration because it reduces the amount of water required by blowdown operations. The purpose of doing this is to decrease water usage in order to reduce water service and sewage disposal costs.

The cycles of concentration in the demonstration systems were controlled by volumetric ratio in order to maintain true cycles at elevated concentration ratios, whereas the chemically treated control sites operating at lower cycles had their ratios controlled by a conductivity set point. Each of the cooling towers was equipped with magnetic contact-type water meters, which were installed in the makeup water line and in the blowdown water line. The water meters measured the total amount of water used by each cooling tower and the total amount of water discharged by each cooling tower over the duration of the project. Also, each swamp cooler selected as a demonstration unit had a water meter installed on its feed line to measure the total amount of water used by that cooler over the duration of the project.

2.4.6 Other tasks

After startup of each system the following checks and tasks were performed: (1) calibration of the conductivity probe, (2) calibration of the corrosion probe, (3) assessment of wireless communications for proper access of data, and (4) setup of appropriate composition coupons (mild steel, galvanized steel, and copper) in coupon racks.

* Dip Slides Model 2620810 Paddle Tester, Total Aerobic Bacteria/Yeast & Mold, by HACH Co.
<http://www.hach.com>.

3 Discussion

3.1 Metrics

3.1.1 Biofouling

Biofouling was monitored using dip slides to perform total aerobic bacteria counts on a monthly basis. While there is no set standard for acceptable levels of counts, it is generally held that (a) counts are seldom obtained for less than 10,000 colony-forming units per milliliter (cfu/ml), even when measured immediately after treatment with biocide, due to the constant inoculation of the system, (b) counts of 100,000 – 500,000 cfu/ml (1×10^5 – 5×10^5) indicate a biologically clean system, and (c) when counts exceed 1×10^6 for an extended period, a biocide treatment is warranted.

3.1.2 Corrosion

As noted, corrosion monitoring was conducted according to ASTM D2688, in which a preweighed test coupon is exposed in a recirculating water system for a specified period of time (90 days is recommended). The longer-term corrosion rate is calculated on the basis of test coupon weight-loss, the surface area, and the exposure time. The corrosion rate is expressed in mils per year (mpy) of metal-thickness loss. Table 3 shows the corrosion levels used as a metric for this project, both for carbon steel and copper alloy, as derived from ASTM Manual MNL20-2ND (2005). These are the two most common metals in mechanical systems; the piping is typically mild steel and the heat-exchange tubes are made of copper alloy. Project targets for this technology were less than 5 mpy for carbon steel and less than 0.35 mpy for copper (i.e., not less than “good” for both metals).

Table 3. Corrosion rates, mils per year (adapted from ASTM MNL20-2ND).

Description	Carbon Steel	Copper Alloy
Negligible or Excellent	≤ 1	≤ 0.1
Mild or Very Good	1-3	0.1-0.25
Good	3-5	0.25-0.35
Moderate to Fair	5-8	0.35-0.5
Poor	8-10	0.5-1.0
Very Poor to Severe	>10	>1.0

3.1.3 Scaling

The formation of scale in chillers was monitored by conducting borescope inspections of the tubes in the condensers. Swamp coolers were monitored and documented photographically. Preweighed cooler pads were installed and removed at 60 – 90 day intervals to measure the weight gain at the treated vs. the untreated sites. There are no industry standards for these tests, but less scaling was considered to be the better result.

3.1.4 Water analysis

Monthly samples were taken of raw makeup water and water in the cooling systems and analyzed in accordance with the test methods below.

- *ICP Total Metals: Calcium, Copper, Iron, Magnesium, Zinc*: EPA Method 200.7, Rev. 4.4, "Methods for the Determination of Metals in Environmental Samples - Supplement 1," EPA 600/R-94/111, EMSL, Cincinnati, Ohio, May 1994.
- *Anions by Ion Chromatography (Chloride)*: EPA Method 300.0, Revision 2.1, "Methods for the Determination of Inorganic Substances in Environmental Samples," EPA-600/R-93-100, August 1993.
- *Alkalinity (Bicarbonate as CaCO_3 , Carbonate as CaCO_3 , Hydroxide as CaCO_3 , Total as CaCO_3)*: Standard Method 2320 B, "Standard Methods for the Examination of Water and Wastewater," 20th Edition, APHA – AWWA – WPCF, Washington, D.C., 1998.
- *Conductivity*: Standard Method 2510 B, "Standard Methods for the Examination of Water and Wastewater," 20th Edition, APHA – AWWA – WPCF, Washington, DC, 1998.
- *Hardness (Calcium as CaCO_3 , Calcium/Magnesium as CaCO_3)*: Standard Method 2340 B, "Standard Methods for the Examination of Water and Wastewater," 20th Edition, APHA – AWWA – WPCF, Washington, D.C., 1998.

The data were collected in order to document the quality of both the feed water as well as changes in the water as it cycled in the cooling systems.

3.2 Results

All tables containing the field data are in presented in Appendix B. It includes

- chemical analysis of the makeup water from each site
- results from the monthly samples collected and analyzed by third-party laboratories
- total aerobic bacteria counts obtained from monthly samples
- corrosion coupon results from quarterly samples
- total water use from each location (makeup and blowdown)
- water conservation calculations
- swamp cooler pad condition.

3.2.1 Biofouling

Data for total aerobic bacteria (TAB) counts is shown in Appendix A, Table A9. The data show no significant difference in bacteria counts between any of the demonstration and control sites at each location. The demonstration systems maintained the same level of biological control as the chemical treatment programs.

3.2.2 Corrosion

Data from the corrosion coupons and electrical resistance corrosion probes is shown in Appendix A, Tables A10 through A13. The data shows no difference between the demonstration system sites and the Control sites. In all locations, corrosion rates for copper and mild steel were maintained well below the target rates of 0.35 and 5 mpy respectively. Warner Robins AFB, with its low mineral content and low pH water, showed the highest average corrosion rates, but the Zeta Rod system kept them well within the set target rates. Low corrosion rates at the other demonstration system sites were expected since the technology capability is based on operating the towers at high cycles of concentration, which has the effect of producing a noncorrosive environment.

3.2.3 Scaling

The scaling-control results require more detailed discussion. Appendix B contains information on the borescope inspections performed at Fort Irwin, Fort Huachuca, and Warner Robins as well as photographic evidence of the tubes from the evaporative condensers at Davis-Monthan.

3.2.3.1 Warner Robins

The condenser tubes from both chillers at Warner Robins remained clean during the two-year project. No scale deposits were formed on the surface

of either condenser. The tubes in the demonstration chiller actually showed a reduction in the amount of the original deposit layer found in the tubes. During the first inspection, the condenser tubes appeared to have a white deposit entirely coating the tube surfaces. This layer was not thick, and tube surfaces could be clearly seen. During the last borescope inspection (December 2011) the inspected tubes showed clean copper surfaces without the white deposit in several locations.

3.2.3.2 *Davis-Monthan*

No new scale deposits were observed on the surfaces of the marked tubes that were cleaned when the project began. The control unit showed some scale formation on some of the lower tubes during a period (April – May 2011) when the blowdown mechanism for the condenser failed and the unit was allowed to operate without blowdown (see Tables A3 and A14) at very high cycles of concentration.

3.2.3.3 *Fort Huachuca*

Between August 2009 and February 2010, the Zeta Rod demonstration cooling tower operated without the use of any chemicals at 5 cycles of concentration (see Table A15). During the February 2010 borescope inspection, an old Carrier chiller was decommissioned, and when opened, several tubes were found to have severe obstructive fouling. Upon inspection, it was determined that the tubes had been physically plugged from debris introduced from the cooling tower basin. No-flow zones were created, which in turn led to selective clogging of the tubes. The second chiller (a Trane unit that had been operating for one 1 year under the same treatment) was opened for inspection, and the tubes showed no sign of blockages or deposition. This finding corroborated the analysis of the cause of blockage in the old chiller. In spite of the evidence presented, and because a brand new chiller had been placed in operation to replace the decommissioned chiller, plant personnel elected to reintroduce chemicals to the cooling tower and operate it under a hybrid program of chemicals and Zeta Rod treatment. At that point in time, the tower blowdown control was returned to the chemical treatment program controller and cycles of concentration (CC) reduced to less than 3. Borescope inspections in January 2011 and December 2011 showed clean tubes in the demonstration unit under the hybrid treatment, but without the water savings that were being obtained using the Zeta Rod technology alone.

Of note, the chemically treated chiller (control location) showed similar fouling of several tubes during the January 2011 and December 2011 inspections, illustrating the importance scheduled maintenance.

3.2.3.4 *Fort Irwin*

The condenser tubes in the demonstration system treated chiller showed improvement during the two-year project, as revealed during the borescope inspections. Zeta Rod technology proved to be capable of controlling scaling under conditions with a very high scaling potential, while providing water savings by maintaining high cycles of concentration.

The control site showed a slight layer of scale on the tube surfaces during the first borescope inspection in February 2010. During the second inspection, in January 2011, the condition of the tubes had significantly worsened. A heavier, evenly distributed layer of scale was present throughout the surface of all the tubes. The tubes in the first pass (upper half) showed a lesser amount of deposit, as would be expected, because the water temperature is lower in the first pass. Plant personnel indicated that there had been a component failure in the chemical feed pump that had resulted in failure to supply chemicals to the water for a period of 2 – 3 weeks. The borescope inspection of December 2011 showed an even thicker layer of scale on the surface of all tubes and the tube sheet. On this occasion, plant personnel reported a repeated problem with the chemical feed pump lasting 4 – 6 weeks.

These events provided important information with regards to the capability of the demonstration technology. In this instance, the Zeta Rod system operated for two years without the use of any chemicals at high cycles of concentration and developed no scale on the tubes. The control tower, running at lower cycles of concentration and using the same water, developed a significant amount of scale on the condenser tubes when it operated without chemical water treatment just for a short period of time.

3.2.4 Water conservation

Tables A14 through A17 (Appendix A) show the water meter data collected at all sites with regards to makeup and blowdown water use.

Operating a cooling tower at higher cycles of concentration reduces the amount of blowdown from the tower and therefore, reduces the amount of makeup water by the same volume.

Although the sites for this demonstration were selected to be similar in size and operation, it was not possible to compare the water use from a Zeta Rod application to a control unit if the cooling systems did not operate for the exact same amount of time and at the exact same load. Difference in run hours and heat loads will result in different volumes of water used. However, it is possible to calculate how much makeup water the demonstration applications would have used and discharged had they been operating at the same lower cycles of concentration as the control units. This approach gives a much more accurate measure of the water savings achieved (or, in the case of Fort Huachuca, missed).

The process for estimating water savings is straightforward. Each tower was equipped with a makeup and blowdown water meter. From the water meter data, two pieces of information can be obtained:

1. amount of water evaporated by the cooling tower
2. cycles of concentration.

The following equations for cooling towers can be then applied:

$$EV = MU - BD \quad \text{Eq 1}$$

$$CC = MU/BD \rightarrow MU = CC \times BD \quad \text{Eq 2}$$

where

EV = evaporation

MU = makeup

BD = blowdown

CC = cycles of concentration.

Substituting Eq 2 into Eq 1, the following equation for BD as a function of CC can be obtained:

$$BD = EV/(CC-1) \quad \text{Eq 3}$$

The evaporation rate for any given cooling tower depends on the environmental conditions, and not on the cycles of concentration at which the tower is operating or the water-treatment method used. In other words, the same amount of water will be evaporated regardless of the cycles of concentration at which that particular tower is operating. The amount of blowdown required by a cooling tower operating at any given CC can be calculated using Eq 3.

This procedure was applied to determine the estimated savings (or missed savings opportunity) in the Zeta Rod towers.

3.2.4.1 Davis-Monthan Building 263 (Zeta Rod application)

Water savings for Davis-Monthan demonstration application are divided into two periods. The first covers water use from August 2009 through October 2010. The second period covers the data collected from November 2010 through July 2011. Table A18 shows the calculated monthly and total water savings.

During the first period, the blowdown-control system operated without incident, maintaining adequate control in the tower. However, a problem with the settings in the makeup float valve, starting in November 2010, continued without being properly addressed. This caused the tower to run with constant overflow during the periods when the condenser was not operating. Consequently, a significant amount of water was discharged from the condenser without being metered. Therefore, it is not possible to estimate from the data the volume of water that evaporated or a basis to calculate water savings or waste.

The problem was worse during the cold months, when the condenser was shut down for extended periods. In the summer months, when the unit was running constantly during the day and the evaporation rate was at its highest, the problem did not occur. This issue highlights the importance of an adequate maintenance program for evaporative cooling systems.

For the period during which proper control was maintained, makeup and blowdown savings (compared to a setting of 3.4 cycles of concentration) totaled 86,297 gallons. This represented savings of 11% for makeup and 37% for blowdown.

3.2.4.2 Fort Huachuca SCP (Zeta Rod application)

Water savings for this site were also calculated for two different periods of time. As previously explained, the cooling tower at the SCP operated under Zeta Rod treatment only, and at high cycles of concentration, between August 2009 and February 2010; and under a combined Zeta Rod and chemical water-treatment program, at low cycles of concentration, between March 2010 and August 2011.

Table A19a shows the calculated monthly and total water savings for the first period, and Table A19b shows the missed savings opportunity had the tower been allowed to operate at 5 cycles of concentration as it did during the first period.

During the first period, makeup and blowdown achieved water savings (compared with the tower operating at 3 cycles of concentration) were 439,496 gallons, representing 18% savings for makeup and 54% for blowdown. During the second period, makeup and blowdown water savings that were missed compared with the amount that would have been saved had the tower operated at 5 cycles of concentration amounted to 1,637,611 gallons, representing lost savings opportunity of 19% for makeup and 53% for blowdown.

3.2.4.3 Fort Irwin, Building 263 (Zeta Rod application)

Water savings at this location were the most significant given the low cycles of concentration (1.5) that were being maintained in the control site. Table A20 shows the monthly and total water savings.

Calculated total water savings for this site were 2,247,610 gallons, an average of 73,357 gal/month. This represented savings of 43% for makeup and 64% for blowdown.

3.2.4.4 Warner Robins, Chiller #2 (Zeta Rod application)

Table A20 contains the data from Chiller #2. It is worth noting that problems with the diaphragm-type blowdown valve between May 2010 and October 2010 caused the cooling tower to operate at low cycles of concentration (i.e., 6). The valve was replaced with a motor-driven ball valve and the problem was corrected.

Estimated overall water savings were 1,027,002 gallons, an average of 124,032 gal/month). This represented savings of 6% for makeup and 45% for blowdown.

However, the period of March 2011 through August 2011 better represents the water savings achieved under the demonstration technology while running at 15 cycles of concentration, compared with 6 cycles maintained in the control tower. During that period, calculated savings were 744,195 gallons, representing savings of 10% in makeup and 64% in blowdown.

3.2.5 Swamp cooler demonstration problems

The demonstrations involving swamp coolers at Fort Huachuca and Fort Irwin were compromised by problems with the project schedule, project design, and coordination between personnel and contractors. As a result, useful data were supplied only by one unit during one season (data shown in Appendix A, Tables A22 and A23).

3.2.5.1 Project schedule

Swamp coolers operate only during late spring and summer at the demonstration sites. The original project plan provided for three full cooling seasons (the summers of 2009, 2010, and 2011) to evaluate differences in the amount of mineral deposition formed on the pads of demonstration and control units. However, because the project began late in summer 2009, a full set of data for the first cooling season was not available, reducing the planned amount of data by one-third.

3.2.5.2 Project design

The original demonstration protocol included a water meter for each monitored cooler and one preweighed cooler pad to be used as a scaling coupon. After the first complete swamp-cooler run (summer 2010), two problems were discovered.

First, some coolers had excessive overflow due to a malfunction of the makeup float valves, nullifying the validity of the water-consumption data. Second, internal water distribution lines in some control coolers were clogged, reducing water supplied to the associated preweighed pad. The combined effect of these problems was to render second-season data unusable.

During the last scheduled cooling season at Fort Huachuca, a full set of pads was installed to all demonstration and control swamp coolers at Fort Huachuca, and a full set of pads was installed to one demonstration cooler and one control cooler Fort Irwin. The idea behind the adjustment was that by installing a full set of preweighed pads, it would be possible to monitor the total weight gain of all the pads combined irrespective of the cooler's internal water-distribution pattern.

3.2.5.3 Coordination

A miscommunication between the maintenance contractor and the building operators at the Fort Irwin Zeta Rod swamp-cooler site resulted in the coolers not being used at all during summer 2011. As a result, portable coolers were procured and brought into the maintenance bays, eliminating the third cooling-season demonstration at Fort Irwin.

3.2.5.4 Summary

Due to the problems described above, only the third cooling season at Fort Huachuca produced any useful swamp cooler demonstration data. Based on those data (Table A22), the control coolers measured 20.8% more accumulated mineral deposits than the demonstration units, when not accounting for water consumption amounts; or 23% higher deposit accumulation when accounting for the water use.

The cooler pad weight gain due to mineralization in the demonstration system (grams per square meters unit area) was 1,535.6 g/m², compared to 1,856.3 g/m² for the control unit.

If water consumption is included in the calculation, then the total weight gain in the demonstration system pads per unit of area and volume was 40.3 g/m²m³, compared to 49.6 g/m²m³ for the control unit pads.

The data show promising results, but more controlled observation would be needed to produce an adequate data set for analysis.

3.3 Lessons learned

Remote monitoring technology provided daily information on each system, but the information could not usually be acted upon promptly because of limitations of the contract with the chemical maintenance

company. Identical monitoring systems were set up on both the demonstration systems and the control systems. On several occasions, problems were detected in the control units, which the manufacturer immediately relayed to the installation personnel. However, installation personnel were often unable to provide for timely corrective action because of the terms of the chemical-treatment contract. Such contracts typically only require monthly visits by the chemical company, and do not provide for off-schedule visits. This kind of problem could be avoided if contracts were written to include timely response by the company to problems reported by installation personnel.

The only technical problem encountered during evaluations arose where the Zeta Rod system was installed on an established chiller system with scale in the pipes. The treated water dislodged scale, allowing it to flow through the pipes. Some chunks became lodged in chiller tubes, causing restricted flow and eventual plugging of several tubes. This problem was not seen at other installations, where standard filters removed suspended particles from the water. It is suggested that when capacitance-based water treatment technology is installed on a cooling system that may have some scaling, an effective filter should be installed to prevent loose scale from circulating and becoming trapped in chiller pipes.

4 Economic Analysis

4.1 Costs and assumptions

Alternative 1 (current technology). Cooling tower water-treatment program incurs the following types of costs:

- Startup—includes the controller, instrumentation, chemical feed pumps, blowdown valve, corrosion coupon rack, and installation costs.
- Chemicals—the rule of thumb for estimating chemical costs when the actual figure is not available, as occurred in this case, is to estimate \$1–2 per ton of refrigeration* (RT) per month. For this analysis an average of \$1.50 per ton per month is used. For example, a 1,000 RT system would consume an average of \$1,500 worth of chemicals per month.
- Water—depending on the location of the installation, costs related to the water used and discharged by the cooling towers are either charged at separate rates or a blanket rate.
- Service fee—includes periodic visits to the site (usually one per month) to perform water analysis, check calibration of the instrumentation, remove corrosion coupons on a quarterly basis, take inventory of chemicals on site and reorder as necessary, and provide monthly reports to the customer.
- Borescope inspection—not every chemical provider offers this service, but it is recommended that chillers and condenser tubes are opened and inspected annually.
- Tube cleaning—while not part of the chemical program, it is a recommended maintenance practice to brush the tubes of the condenser during the annual inspection.

Alternative 2 (demonstrated technology). The Zeta Rod technology had the following associated costs:

- Startup —includes costs of all hardware components of the system plus installation, and is typically higher than the startup cost for chemical treatment.
- Chemicals—no cost.

* 1 ton (refrigeration) = 21,000 British thermal units per hour (Btu/h).

- Water—since cooling towers operate at higher cycles of concentration than under chemical treatment, water costs are significantly lower.
- Monitoring—an annual fee that includes remote monitoring of the system and report preparation. Under a conventional monitoring service contract, site visits are required on a quarterly basis, as opposed to a monthly basis as is common with the chemical treatment program.
- Borescope inspection—this is also recommended when using capacitance-based treatment, either on an annual or biannual basis.
- Tube cleaning—also recommended as part of preventive maintenance, but on a biannual basis instead of every year.

CPC project-specific cost distribution. Because this treatment technology was evaluated as part of a demonstration program, more rigorous monitoring was required than indicated above. For this project, monthly site visits were specified. Monthly water samples from both the demonstration towers and the control towers were collected and sent to an independent laboratory, adding significant costs when compared with standard in-house testing. Also, the total cost of this demonstration included monitoring equipment for the control sites (i.e., standard chemically treated systems) that would not be required where capacitance-based water treatment is implemented. Additionally, over 2 years, the project required four borescope inspections for both the demonstration and control systems.

For this economic analysis, the 2 year intense monitoring and service costs for both the demonstration and control sites are included for the first 2 years of service. The initial cost also includes the monitoring equipment acquisition and installation. After Year 2, the annual service fee for the demonstrated technology and the water monitoring fee are adjusted to reflect a conventional monitoring and service contract fee.

Water cost calculations. Table 4 shows the water costs provided for each of the four military installations.

Table 4. Water cost (\$/1,000 gal).

Installation	Makeup	Blowdown
Fort Irwin	\$3.50	
Fort Huachuca	\$1.56	\$1.37
Davis-Monthan AFB	\$0.63	\$3.62
Warner Robins AFB	\$1.00	\$1.00

Fort Irwin has a consolidated price for makeup and sewer charges, thus they show no separate cost for blowdown. Fort Huachuca and Davis-Monthan AFB are billed separately for makeup and sewer by the local utility company, and the price difference takes into account the cost to treat waste water. No water cost information was made available for Warner Robins AFB. An average value of \$1.00/1,000 gal based on the costs from the other bases was used for the analysis.

Table 5 shows the estimated annual water use for each site operating at the cycles of concentration used by the control sites and the cycles of concentration used in the Zeta Rod applications.

Table 5. Estimated annual water use (x 1,000 gal).

	Chemical Treatment			Capacitance-Based Treatment		
	CC	Makeup	Blowdown	CC	Makeup	Blowdown
Fort Irwin	1.5	2,578	1,473	3	1,657	552
Fort Huachuca	2.75	8,698	3,163	5	6,919	1,384
Davis-Monthan AFB	3.4	958	282	5	845	169
Warner Robins AFB	6	11,946	1,991	15	10,666	711

Table 6 shows the estimated annual water cost for makeup, blowdown, and total for each site with reference to the costs shown in Table 4.

Table 6. Estimated annual water cost.

	Chemical Treatment			Capacitance-Based Treatment		
	CC	Makeup	Blowdown	CC	Makeup	Blowdown
Fort Irwin	\$9,023	\$0	\$9,023	\$5,800	\$0	\$5,800
Fort Huachuca	\$13,569	\$4,333	\$17,902	\$10,793	\$1,896	\$12,689
Davis-Monthan AFB	\$603	\$1,020	\$1,623	\$532	\$612	\$1,144
Warner Robins AFB	\$11,946	\$1,991	\$13,937	\$10,666	\$711	\$11,377

Chemical cost calculations. Installation personnel were not able to provide an annual chemical cost for the individual sites used in the project because of their bulk buying practices or contracts. However, an informal market survey suggests that average annual chemical costs range between \$1.00 and \$2.00 per ton of refrigeration per month. The analysis was made using a \$1.00, \$1.50, and \$2.00 per ton per month values. Plant personnel agreed with these estimated values.

Table 7 shows the estimated annual chemical costs for each site, given the size of the units and their annual use.

Table 7. Estimated annual chemical costs.

		Operation	Estimated Annual Chemical Cost		
	System RT	Months/yr	\$1/(RT*month)	\$1.5/(RT*month)	\$2/(RT*month)
Fort Irwin	350	8	\$2,800.00	\$4,200.00	\$5,600.00
Fort Huachuca	850	12	\$10,200.00	\$15,300.00	\$20,400.00
Davis-Monthan AFB	110	12	\$1,320.00	\$1,980.00	\$2,640.00
Warner Robins AFB	1,500	8	\$12,000.00	\$18,000.00	\$24,000.00

The cost figures used to calculate the ROI are as follows:

Total Investment for the Project:	\$500,829
Baseline Costs Year 1, control towers:	\$216,223
Baseline Costs Year 1, Zeta Rod application:	\$263,292
Baseline Costs Year 2, control towers:	\$148,677
Baseline Costs Year 2, Zeta Rod application:	\$97,722
Baseline Costs Years 3–30, control towers:	\$127,077
Baseline Costs Years 3–30, Zeta Rod application:	\$47,437

Year 1 baseline costs for control applications 1 covered remote monitoring equipment and installation, and control equipment required to start a chemical program. Also covered were all expenses incurred during Year 1 for monitoring, water and coupon analysis, borescope, travel expenses for site visits, chemicals. Year 2 costs covered the same as Year 1, minus startup costs. Years 3–30 include only chemical and water costs, monthly visits by the provider, and borescope inspections.

Year 1 baseline costs for Zeta Rod applications cover equipment and installation startup costs; all the expenses incurred during Year 1 for monitoring, water and coupon analysis, borescope, travel expenses for site visits, and water used. Year 2 costs cover the same expenses, minus startup. Years 3–30 include water costs, a remote monitoring service program (quarterly visits), and borescope inspections.

4.2 Projected return on investment (ROI)

The ROI for this technology was computed using methods prescribed by Office of Management and Budget (OMB) Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. Comparing the costs and benefits of the two alternatives, the 30-year return on investment after implementing the new technology (Alternative 2) is \$1,689,506 (see Table 8). Based on an expenditures of \$500,829 the return on investment ratio is 3.37.

Table 8. ROI calculation.
Return on Investment Calculation

Investment Required		500,829
Return on Investment Ratio	3.37	Percent 337%
Net Present Value of Costs and Benefits/Savings	878,279	2,567,786
		1,689,506

A Future Year	B Baseline Costs	C Baseline Benefits/Savin gs	D New System Costs	E New System Benefits/Savin gs	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	216,223	47,069	263,292.0		290,063	202,082	-87,981
2	148,677		97,722.0	50,955	85,350	174,359	89,008
3	127,077		47,437.0	79,640	38,723	168,743	130,020
4	127,077		47,437.0	79,640	36,190	157,704	121,515
5	127,077		47,437.0	79,640	33,823	147,389	113,567
6	127,077		47,437.0	79,640	31,607	137,736	106,128
7	127,077		47,437.0	79,640	29,539	128,723	99,184
8	127,077		47,437.0	79,640	27,608	120,309	92,701
9	127,077		47,437.0	79,640	25,801	112,433	86,632
10	127,077		47,437.0	79,640	24,112	105,074	80,962
11	127,077		47,437.0	79,640	22,537	98,211	75,674
12	127,077		47,437.0	79,640	21,062	91,782	70,720
13	127,077		47,437.0	79,640	19,686	85,788	66,101
14	127,077		47,437.0	79,640	18,396	80,165	61,769
15	127,077		47,437.0	79,640	17,191	74,914	57,723
16	127,077		47,437.0	79,640	16,067	70,015	53,948
17	127,077		47,437.0	79,640	15,019	65,447	50,428
18	127,077		47,437.0	79,640	14,037	61,168	47,131
19	127,077		47,437.0	79,640	13,116	57,157	44,041
20	127,077		47,437.0	79,640	12,258	53,416	41,158
21	127,077		47,437.0	79,640	11,456	49,922	38,466
22	127,077		47,437.0	79,640	10,707	46,656	35,949
23	127,077		47,437.0	79,640	10,004	43,597	33,592
24	127,077		47,437.0	79,640	9,350	40,744	31,394
25	127,077		47,437.0	79,640	8,738	38,077	29,339
26	127,077		47,437.0	79,640	8,169	35,597	27,428
27	127,077		47,437.0	79,640	7,633	33,261	25,628
28	127,077		47,437.0	79,640	7,135	31,090	23,956
29	127,077		47,437.0	79,640	6,670	29,064	22,395
30	127,077		47,437.0	79,640	6,233	27,163	20,929

5 Conclusions and Recommendations

5.1 Conclusions

Current results of Zeta Rod technology evaluation cover 2 years of demonstration at Warner Robins AFB and Fort Irwin, which are consistent with results obtained after 4 years of demonstration at Fort Huachuca and Davis-Monthan AFB (the latter performed partially under other funding). Taken together, these locations provide a representative variety of climatic conditions and source-water characteristics. The current demonstration has produced sufficient data to illustrate that the nonchemical, capacitance-based treatment technology and methods are fully functional across a wide range of water and climate conditions, and are applicable to different HVAC equipment designs.

The results indicate that the Zeta Rod system is fully effective in controlling corrosion in institutional-type cooling systems. It is also as effective in controlling scale and bacteria populations as the use of conventional chemical additives. In addition, the use of the remote-monitoring instrumentation and purpose-developed operational protocols resulted in a significant level of water conservation, providing recurring cost reductions while fully protecting high-value capital equipment.

The remote-monitoring and alarm capabilities of demonstrated system were a key component of the success of this long-term demonstration. Alarms were generated when otherwise-normal operating problems arose, directing early attention to these situations before problems became more costly to address. These technologies, in concert with normal maintenance activity, enabled facility personnel to more reliably address problems such as a stuck valve, a power failure, or out-of-adjustment equipment. During this demonstration, numerous maintenance-related issues were detected remotely, reported, and addressed promptly.

The water-conservation benefits of the demonstrated technology are directly relevant to Army Net Zero water efforts, and similar initiatives in the other military departments. Cooling towers present a significant opportunity for implementation of water-conservation technologies because the potential water-volume savings can exceed the amount of all other facility

water use. The documentation of more than 20 percent reductions in fresh water use and 50 percent reductions in blowdown wastewater disposal represent water volume savings that in most cases exceeded any other conservation measure available to a facility (e.g., low-flow fixtures). Coupled with the opportunity for reuse of chemical-free wastewater from the cooling towers, a significant water-conservation benefit related to the use of this technology has been successfully demonstrated.

Evaluation of the effectiveness of Zeta Rod technology on swamp cooler installations was thwarted by data-collection difficulties, but the data generated during the final season on a single pair of coolers appears to be credible. Those data indicate that Zeta Rod technology may successfully be applied to swamp coolers, but additional evaluations would be needed to provide enough data for full assessment and validation.

5.2 Recommendations

5.2.1 Applicability

Based on the results of this dem/val, this technology is considered to be applicable to a wide range of water chemistries and cooling system sizes. The user's ROI will vary based on the size of the cooling system, local water costs, etc., but significant savings in most cases are expected. It is therefore recommended that Army installations consider implementing the demonstrated water-treatment system at all locations currently using chemical treatment of water in central cooling systems.

It is noted that data generated during the final season on a single pair of swamp coolers appears to be credible and indicates that Zeta Rod implementation can be beneficial. However, based on the results of this project, the limited amount of data generated cannot be taken as a complete validation of the technology for swamp coolers. Additional evaluations would be necessary to produce more data and a higher level of confidence in any recommendation for swamp cooler implementation.

It also is stressed that this work documented one system based on developing a zeta potential in a cooling water system using a high-voltage direct current (DC) capacitor. Other nonchemical water-treatment systems, based on alternating current as well as on magnetic technology, are currently being marketed. Those systems were not evaluated in this project,

and their performance may significantly differ from DC-based system evaluated in this demonstration.

5.2.2 Implementation

After the initial demonstration of this technology (Beitelman 2009), HQUSACE published interim implementation guidance in Engineering and Construction Bulletin ECB 2012-10, *Non-Chemical Treatment of Cooling Tower Water* (3 April 2012). That guidance was dated to expire on 3 April 2014, but the implementation language is suitable for incorporation into Unified Facilities Guide Specifications Section 23 25 00, *Chemical Treatment of Water for Mechanical Systems*, which is the primary DoD reference for specifying mechanical system water treatment practice.

It is recommended that the draft language presented in Appendix C be considered for incorporation into UFGS 23 25 00. The suggested implementation language includes a designer's note based on text from ECB 2012-10, plus new language for specifying nonchemical, high-voltage, capacitance-based water treatment technology for mechanical systems.

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Appendix A: Data from Demonstration Sites

Makeup water analysis

Table A1 shows the chemical composition of the makeup water at each military base. Given previous history of the stability of the water at each location, only one sample was collected and sent to a lab for analysis at the beginning of the project.

TABLE A1. Makeup (MU) Water Analysis for Each Location				
MU Water Composition	Warner Robins AFB	Davis- Monthan AFB	Fort Huachuca	Fort Irwin
Conductivity (uS)	115	350	330	960
TDS ppm	57.5	175	165	480
pH	6.5	7.2	8.2	8
Hardness Ca	9.5	95	98	61
Hardness Ca & Mg	11	120	130	78
Ca		38	39	24
Mg		5.6	8.1	4.2
Chloride	31.7	5.4	6.9	100
Alkalinity Bicarbonate	54	140	150	130
Alkalinity Total	54	140	150	130
Silica	3.6	23	26	49

Tables A2 through A8 contain the lab results from the monthly water samples collected at each site.

Table A2. Davis-Monthan Bldg 2301 (Zeta): Cooling Water Analysis

Date	Hard- ness Ca	Hardness (Ca & Mg)	Ca	Cu	Fe	Mg	Zn	Chloride	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Cond (uS)	Silica	pH
08/17/09	190	250	77	0.043	ND	13	0.055	15	170	44	210	620	57	
09/25/09	120	160	46	ND	ND	11	ND	19	120	88	210	590	61	
10/21/09	86	110	35	ND	0.36	4.8	ND	6	130	0	130	360	27	
11/13/09	110	140	43	ND	ND	8.3	ND	10	130	52	180	500	43	
12/10/09	130	160	51	0.19	1.4	7.2	0.19	7.6	140	ND	140	370	27	
01/20/10		110	35	0.02		5.3		6.4	110	32	140	360	26	
02/23/10	89	120	36	ND	ND	6.7	ND	24	74	100	170	720	46	
03/15/10		150	37	0.025	ND	15	0.19	27	160	76	240	880	90	
04/19/10	96	170	39	ND	ND	18	ND	28	140	120	260	910	110	
05/11/10	92	170	37	ND	ND	20	0.058	36	160	140	290	1100	130	8.7
06/10/10	67	140	27	ND	ND	18	ND	32	120	130	250	1000	140	8.7
07/16/10	89	190	35	ND	ND	25	ND	41	82	160	250	1300	160	
08/16/10	91	200	37	0.032	0.54	27	0.17	43	140	180	320	1300	160	8.7
09/13/10	47	100	19	ND	ND	13	ND	31	180	140	320	1000	160	8.8
10/13/10	46	96	19	ND	ND	12	0.049	21	100	170	270	820	120	8.7
11/03/10	67	110	27	ND	ND	11	ND	19	100	140	240	700	90	
12/06/10	81	110	32	ND	ND	6.9	ND	9.2	100	64	170	450	46	8.2
01/05/11														
02/01/11	98		39	0.045	0.37	6.2	0.098	8.1	94	48	140	360	33	8.2
03/01/11	86	110	34	ND	ND	5	ND	8	86	60	150	380	29	8
04/05/11	100	150	40	ND	ND	13	ND	17	120	92	210	650	75	8.4
05/10/11	81	140	32	ND	ND	15	ND	30	150	88	240	970	110	8.8
06/08/11	65	120	26	ND	ND	13	ND	24	140	80	220	850	99	8.4
07/21/11	58	140	23	ND	ND	19	ND	42	150	110	260	1300	150	8.8
08/26/11		160									220	850	105	8.61

Table A3. Davis-Monthan Bldg 1610 (Control): Cooling Water Analysis

Date	Hardness Ca	Hardness (Ca & Mg)	Ca	Cu	Fe	Mg	Zn	Chloride	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Cond	Silica	pH
08/17/09	240	310	97	0.98	0	17	0	32	260	100	360	950	70	
09/25/09	290	380	120	0.53	ND	22	ND	62	330	76	400	1300	110	
10/21/09	260	320	100	0.22	ND	17	ND	24	280	160	440	1200	94	
11/13/09	220	300	88	0.14	0	18	0	42	260	130	390	1200	100	
12/10/09	250	340	99	0.3	ND	22	ND	58	290	130	420	1400	79	
01/20/10		280	89	0.63		15		75	190		190	1100	70	
02/23/10	280	360	110	0.83	ND	19	0.073	42	370	120	490	1300	99	
03/15/10		350	110	0.25	ND	20	ND	33	270	160	430	1300	97	
04/19/10	240	310	98	0.59	ND	17	ND	42	340	100	440	1100	90	
05/11/10	260	330	100	0.35	ND	16	ND	21	280	170	440	1000	88	8.7
06/10/10	270	340	110	0.22	ND	17	ND	21	210	220	430	1000	96	8.9
07/14/10	300	370	120	0.18	ND	18	ND	64	240	130	370	1200	94	
08/16/10	330	430	130	0.21	ND	22	ND	42	210	260	470	1200	98	8.9
09/13/10	270	330	110	0.18	ND	16	ND	28	250	150	400	920	92	8.8
10/13/10	260	320	110	0.16	ND	14	ND	16	250	180	430	920	84	8.7
11/03/10	260	320	100	0.18	ND	15	ND	49	400	48	440	1100	110	
12/06/10	240	320	98	0.23	ND	19	ND	27	280	200	480	1200	120	8.7
01/05/11	260	340	100	0.33	ND	21	ND	29	330	140	470	1300	110	
02/01/11	270	360	110	0.2	ND	21	ND	28	300	140	430	1100	97	8.8
03/01/11	190	240	74	0.27	ND	12	ND	48	210	76	290	850	66	8.4
04/05/11	260	330	100	0.23	ND	17	ND	66	300	92	390	1100	96	8.3
05/10/11	140	380	57	0.09	ND	59	ND	180	540	230	770	4500	120	9.1
06/08/11	81	250	33	0.53	ND	40	ND	78	340	330	670	7300	150	9.1
07/21/11	240	300	95	0.11	ND	15	ND	51	240	100	340	1100	93	8.7
08/26/11		460									460	1250	114	8.73

Table A4. Fort Huachuca SCP (Zeta): Cooling Water Analysis

Date	Hardness Ca	Hardness (Ca & Mg)	Ca	Cu	Fe	Mg	Zn	Chloride	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Cond	Silica	pH
08/20/09	77	160	31			21		23	170	56	230	540	75	
09/24/09	75	190	30			27		31	180	110	290	710	130	
10/21/09	71	180	28			26		31	180	110	280	670	110	
11/12/09	70	160	28	0.02		21		36	180	100	280	680	120	
12/11/09	75	160	30	0.033	ND	21	ND	31	160	120	280	660	84	
01/20/10		170	21			28		78	290	92	380	1200	150	
02/23/10		320	78	ND	ND	32	ND	33	300	170	470	920	130	
03/16/10		380	110	0.025	ND	28	ND	27	210	300	510	920	110	
04/20/10	310	440	130	0.034	ND	31	ND	36	280	290	570	1000	11	
05/25/10	290	390	110	0.03	ND	26	ND	32	240	240	280	920	95	
06/15/10	280	390	110	0.067	ND	26	ND	33	210	290	490	900	94	8.8
07/22/10	220	300	89	ND	ND	19	ND	19	210	220	430	770	82	8.9
08/16/10	240	340	96	ND	ND	23	ND	16	200	240	450	770	71	8.8
09/15/10	240	340	98	ND	ND	24	ND	18	210	220	440	790	76	8.8
10/21/10	240	330	96	ND	ND	23	ND	18	250	180	430	760	89	8.8
11/08/10		300	84	ND	ND	22	ND	28	150	240	390	770	72	8.7
12/07/10			93	0.033	ND	23	ND	20	200	220	420	770	87	8.9
01/10/11	230	330	92	ND	ND	24	ND	27	200	170	370	760	78	8.8
02/02/11		320	90	ND	ND	22	ND	23	260	130	390	720	76	8.8
03/01/11	240	330	95	ND	ND	22	ND	27	230	180	410	770	83	8.9
04/06/11	220	310	88	ND	ND	21	ND	21	250	180	420	760	78	8.8
05/03/11	180	250	72	ND	ND	18	ND	18	190	110	300	600	61	8.8
06/07/11	230	320	92	ND	ND	23	ND	22	250	140	390	760	74	8.8
07/20/11	340	430	130	0.14	0.84	22	0.17	25	330	170	500	950	94	8.8
08/25/11		440									460	820	78	8.88

Table A5. Fort Huachuca NCP (Control): Cooling Water Analysis

Date	Hardness Ca	Hardness (Ca & Mg)	Ca	Cu	Fe	Mg	Zn	Chloride	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Cond	Silica	pH
08/20/09	350	480	140	0.025		31		28	390	190	590	1100	92	
09/24/09	310	410	120	0.039		26		24	260	250	510	930	100	
10/21/09	280	380	110	0.023		24		24	320	180	510	940	94	
11/12/09	400	500	160	0.2	0.32	25	0.45	27	360	150	510	910	100	
12/11/09	640	790	260	0.56	0.75	35	1.1	28	320	160	480	880	72	
01/20/10		350	100	0.033		22		31	320	170	480	920	89	
02/23/10													72	
03/16/10		300	89	0.027	ND	20	ND	23	240	160	400	770	84	
04/20/10	280	390	110	0.027	ND	26	ND	29	290	200	490	910	95	
05/25/10	320	430	130	0.064	ND	25	ND	31	320	220	530	970	95	
06/15/10	300	400	120	0.022	ND	25	ND	31	280	260	540	950	94	8.7
07/22/10	320	420	130	0.037	ND	24	ND	25	270	230	500	900	95	8.8
08/16/10	320	450	130	ND	ND	33	ND	22	360	250	610	1000	95	8.7
09/15/10	340	460	130	0.082	ND	31	0.066	21	300	220	520	940	96	8.8
10/21/10	290	410	120	0.052	ND	28	ND	22	330	190	520	900	93	8.7
11/08/10			110	0.052		29		32	250	230	480	920	100	8.7
12/07/10			110	0.069	ND	31	0.048	27	280	220	490	910	100	9
01/10/11	300		120	0.2	0.69	34	0.12	32	250	200	450	900	99	8.8
02/02/11	300		120	0.095	0.35	30	0.098	29	280	180	460	840	98	8.9
03/01/11	160		65	0.025	ND	12	ND	13	140	100	250	490	49	8.5
04/06/11	290	400	110	0.026	ND	28	ND	28	340	180	520	930	100	8.7
05/03/11	300	430	120	ND	ND	31	ND	30	320	170	490	940	94	8.9
06/07/11	270	390	110	ND	ND	27	ND	23	320	160	480	890	93	8.8
07/20/11	270	350	110	ND	ND	19	ND	24	330	160	490	940	92	8.9
08/25/11		460									460	832	58	8.77

Table A6. Fort Irwin BLDG 263 (Zeta): Cooling Water Analysis

Date	Hardness Ca	Hardness (Ca & Mg)	Ca	Cu	Fe	Mg	Zn	Chloride	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Cond	Silica	pH
08/14/09	150	220	60	0.03		16		490	290	120	410	4200	90	
09/18/09	110	170	44	ND	ND	14	ND	390	180	200	380	4000	170	
10/27/09	110	150	46	0.17	ND	9.9	ND	300	210	140	350	3500	150	
11/09/09	65	84	26	0.14	ND	4.6	0.12	200	170	76	250	1700	120	
06/30/10	86	120	34	ND	ND	8.2	ND	270	120	160	280	2600	150	8.6
07/27/10	86	130	35	ND	ND	9.7	ND	300	120	140	260	2700	150	
10/15/10	74	120	30	ND	ND	11	ND	280	140	120	270	2500	140	
08/22/11		200						320			240	1730	96	8.85

Fort Irwin BLDG 273 (Control): Cooling Water Analysis														
Date	Hardness Ca	Hardness (Ca & Mg)	Ca	Cu	Fe	Mg	Zn	Chloride	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Cond	Silica	pH
08/14/09	84	110	34			65		150	120	52	180	1400	79	
09/18/09	56	130	23			17		530	180	180	360	5200	140	
10/27/09	39	16	0	0	0	0	0	71	120	0	120	920	60	
11/09/09	45	45	18	0.023	0	0	0	88	130	0	130	940	75	
06/30/10	41	41	16	ND	ND	ND	0.046	40	130	ND	130	940	63	8.0
07/27/10	96	120	38	ND	ND	6.7	ND	160	80	120	200	1500	100	
10/15/10	76	110	31	ND	ND	8.1	ND	160	110	52	160	1300	110	
08/22/11		360						5700			1880	1320	80	9.17

Table A7. Warner Robins Cooling Tower #2 (Zeta): Cooling Water Analysis

Date	Hardness Ca	Hardness Mg	Hardness (Ca & Mg)	Cu	Zn	Chloride	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Cond (uS)	Silica
09/22/09	57		86			32	43		43	362	65
10/29/09	2.2		3.7				50		50	22	
11/18/09	53		80							45	52
01/20/10	30		40			27	25	25		84	11
02/23/10	85		118			79	283	8	291	745	42
03/18/10	11		14			4.9	85		85	163	
04/16/10	14		18			5	125		125	260	19
05/18/10	32		43			31	586	2	588	1126	34
06/21/10	27		39			44	479	41	520	1139	33
07/16/10	38		52			50	770	80	850	1717	42
08/16/10	7		18			46	754	146	900	1437	35
09/14/10	50		61			36	523	46	570	1058	19
10/21/10	4.5		7			24	80		80	781	0.43
11/17/10	3.25	1.72		0.15		29	70	ND	70	160	4.1
12/16/10	4.25	1.72	6	0.029		8.3	72	ND	72	156	2.8
01/27/11	4.75	2.09	6.8	ND		11.2	63	ND	63	143	5.2
02/17/11	27.5	8.2	36	0.65		3.5	100.7	ND	101	300	10
03/24/11	20.5	7.79	28	0.23		14.7	337	25.2	363	815	7.3
04/28/11	30	15.6	45	0.43		84.1	691.2	187.4	880	1922	39
05/26/11	21	22.6	59	0.47		70.8	690.2	138.7	830	1773	37
06/28/11	35	18	52	1.1		99.4	998	270.56	1270	2780	54
07/21/11	30	15.6	46	0.79	0.26	76	855.7	113.62	970	2330	46

Table A8. Warner Robins Cooling Tower #4 (Control): Cooling Water Analysis

	Hardness	Hardness	Hardness			Alkalinity	Alkalinity	Alkalinity		
Date	CA	Mg	(Ca & Mg)	Cu	Chloride	Bicarbonate	Carbonate	Total	Cond	Silica
09/22/09	65		95		30	46		46	360	65
10/29/11	65		99		30	2		2	374	9.5
11/18/09	13		17		3.3	12		12	319	5.9
01/20/10	55		81		65	25		25	245	44
02/23/10	55		85		49	34		34	282	47
03/18/10	20		27		11	174	45	220	425	13
04/16/10	15		21		9	244	8	252	529	34
05/18/10	21		31		20	352	18	370	723	21
06/21/10	24		35		45	485	45	530	1150	33
07/16/10	16		24		30	336	14	350	777	19
08/16/10	17		23		15	292	8	300	521	19
09/14/10	23		33		41	565	84	650	1235	24
10/21/10	18		27		42	355	5	360	177	1.9
11/17/10	13.8	6.97	21	0.21	42	355	ND	360	709	21
12/16/10	23.75	10.66	34	0.13	31.6	518.3	31.45	550	1052	34
01/27/11	7.25	6.56	14	0.38	50	800	99	900	1669	6.3
02/17/11	6.5	29.9	95	0.47	162	1978	630	2610	5190	100
03/24/11	40	20.1	60	1	91.3	1257	471	1730	3630	22
04/28/11	77.5	33.6	110	9.2	184.2	2080.9	1026.52	3110	4520	72
05/26/11	57.5	57.4	93	4.7	217.8	1674.6	454	2130	4470	62
06/28/11	30	15.2	46	0.74	61.6	819.8	59.82	880	1936	46
07/21/11	42.5	16.4	58	0.84	0.12	108	1249.7	199.5	1450	3880
										58

Total Aerobic Bacteria Counts

With each water sample collected, a total aerobic bacteria dip slide was sampled. Table A9 shows the total aerobic bacteria in colony forming units per ml (cfu/ml) obtained after a 48-hour incubation period.

Table A9. Total Aerobic Bacteria (cfu/ml)								
Month	Warner Robins		Fort Huachuca		Fort Irwin		Davis-Monthan	
	Zeta	Ctrl	Zeta	Ctrl	Zeta	Ctrl	Zeta	Ctrl
Aug 09			-	-	1,000,000	-	1,000,000	-
Sep 09			-	-	100	-	-	-
Oct 09	-	-	-	-	1,000,000	-	-	100
Nov 09	100	100	-	1,000	100	1,000	-	-
Dec 09			-	1,000			10	10,000
Jan 10	100	-	-	-			-	-
Feb 10	-	100	-	-			-	-
Mar 10	10	-	-	-			10,000	1,000,000
Apr 10	-	750	100	-			1,000,000	-
May 10	100,000	10,000	-	-			-	100
Jun 10	500	300	1,000	1,000	1,000	-	-	100
Jul 10	100	100,000	-	100	1,000	-	100	-
Aug 10	20	300	-	-			-	-
Sep 10	2,500	50	-	100			-	-
Oct 10	50	-	-	-	-	-	-	100
Nov 10	-	10	-	-			-	-
Dec 10	-	10	-	-			-	-
Jan 11	-	-	100	100			-	-
Feb 11	-	10	-	-			-	10
Mar 11	300	100	-	-			-	-
Apr 11	100	5,000	-	-			10	-
May 11	1,000	50	-	-			-	100
Jun 11	100	-	-	-			-	100
Jul 11	100	1,000	100	100			100	-

Corrosion Coupon Results

Each site was equipped with a 0.75 in. corrosion coupon rack and housed an appropriate alloy steel coupon, copper coupon, and the electrical resistance (ER) corrosion probe. Corrosion coupons were replaced after a minimum exposure time of 90 days and sent to an independent lab* for weight loss analysis.

Tables A10 through A13 and their corresponding graphs show results from the corrosion coupons at all sites. Each site had copper coupons and (with the exception of Davis-Monahan) carbon steel coupons. The Zeta treated evaporative condenser at Davis-Monahan had a galvanized steel structure and the control unit had a stainless steel structure, so coupons of corresponding alloys were installed.

Table A10. Fort Huachuca (FH) Corrosion Coupon Results (mpy)					
		Copper (CDA110)		Mild Steel (C1010)	
Period	Days Exposed	Zeta	Control	Zeta	Control
Aug 09 -Nov 09	86	0.2925	0.3347	0.7043	0.2257
Nov 09 - Apr 10	159	0.0579	0.0667	0.2506	0.1311
Apr 10 - Jul 10	93	0.1968	0.2013	0.3818	0.3388
Jul 10 - Oct 10	90	0.1148	0.0876	0.3217	0.267
Oct 10 - Jan 11	76	0.1593	0.1593	0.2872	0.2017
Jan 11 - Apr 11	90	0.1165	0.1294	0.2038	0.4855
Apr 11 -Jul 11	105	0.1565	0.0965	0.3007	0.3812

* Metal Samples Co. Inc., Post Office Box 8, 152 Metal Samples Road, Mumford, Alabama 36268

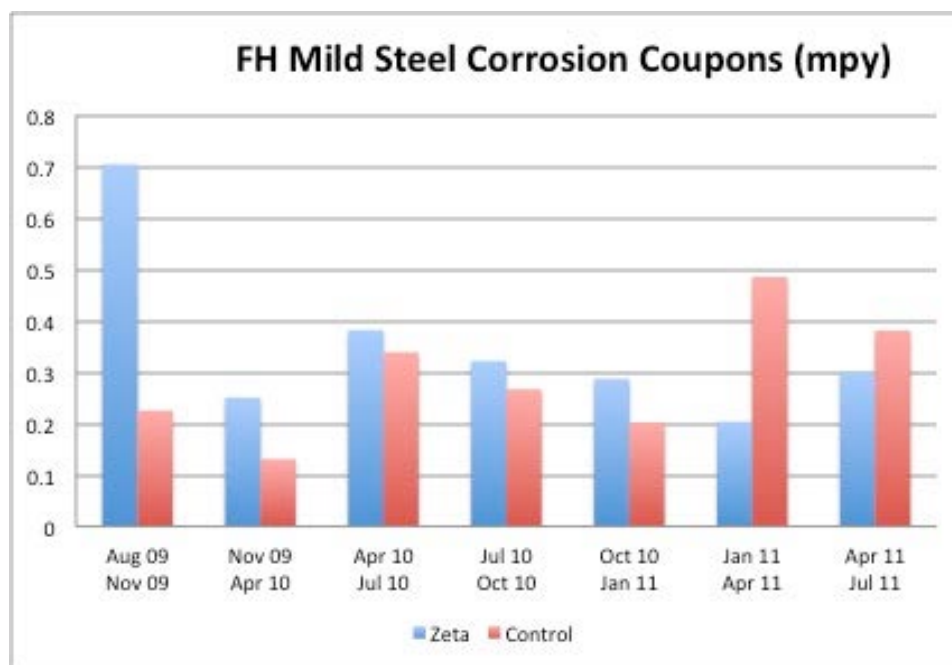
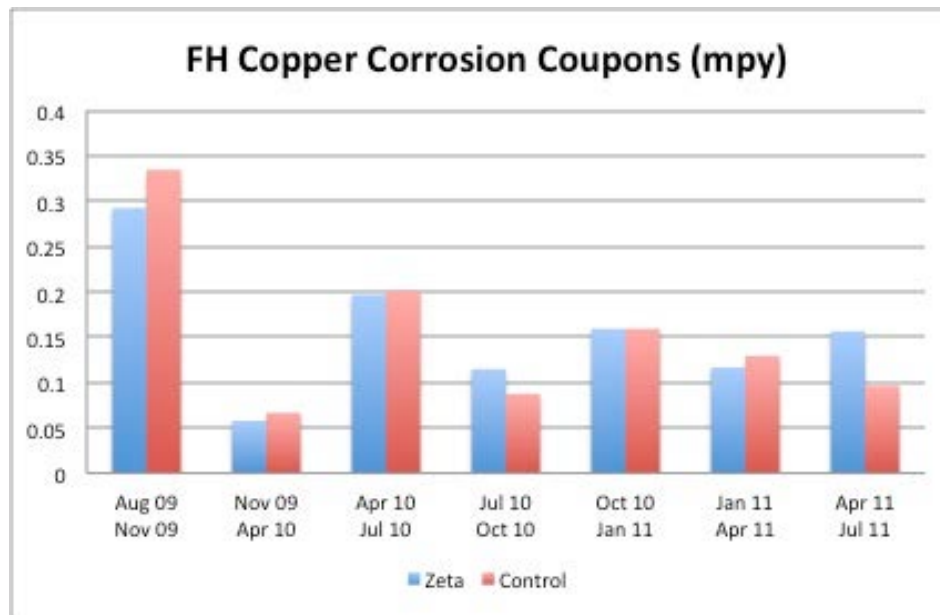


Table A11. Fort Irwin (FI) Corrosion Coupon Results (mpy)					
Period	Days Exposed	Copper (CDA110)		Mild Steel (C1010)	
		Zeta	Control	Zeta	Control
Aug 09 - Nov 09	89	0.2959	0.2067	0.2968	0.3585
Nov 09 - Apr 10	154	0.0665	0.0491	0.2111	0.1857
Apr 10 - Jul 10	106	0.2685	0.3137	1.4226	2.0699
Jul 10 - Oct 10	77	0.5557	0.6485	0.3558	1.6195
Oct 10 - Jan 11	86	0.367	0.2634	0.6782	0.7599
Jan 11 - May 11	116	0.1298	0.126	0.8322	0.194
May 11 - Aug 11	112	0.2852	0.1692	1.5078	1.4199

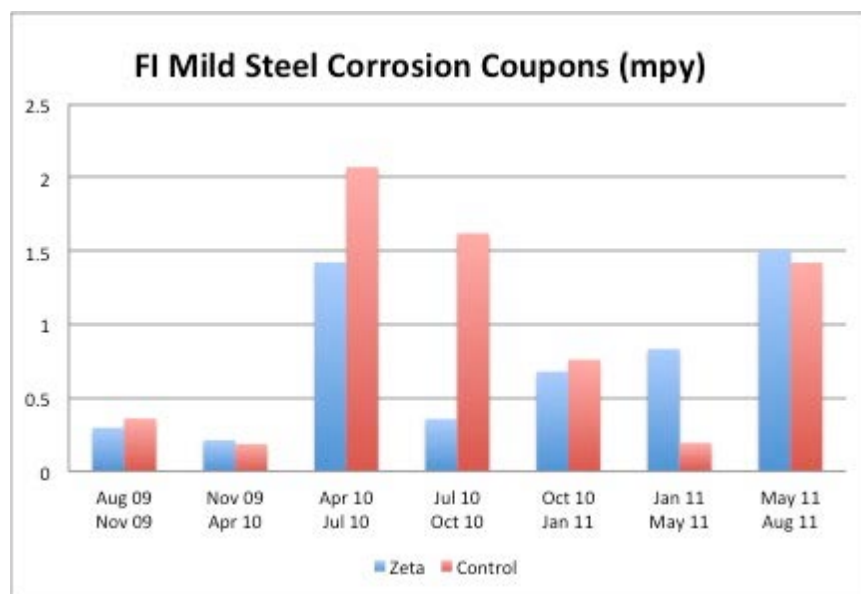
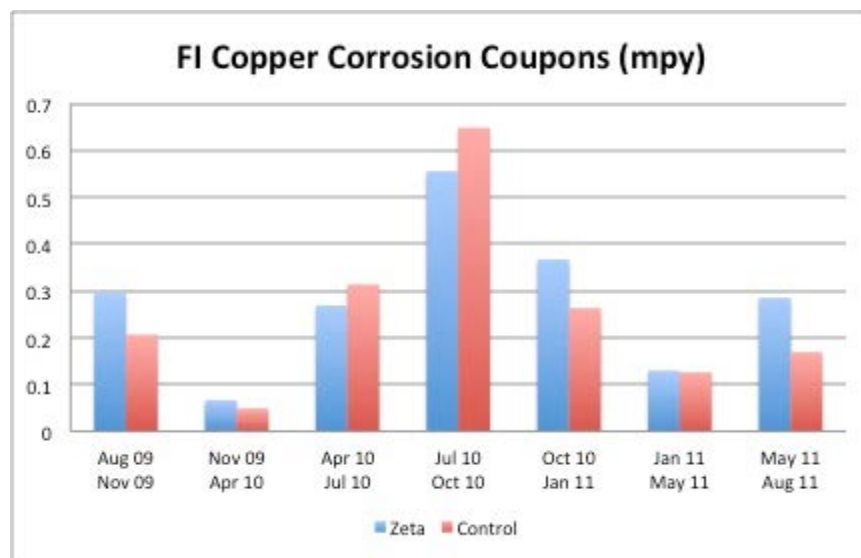


Table A12. Warner Robins (WR) Corrosion Coupon Weight Loss (mpy)					
Period	Days Exposed	Copper (CDA110)		Mild Steel (C1010)	
		Zeta	Control	Zeta	Control
Aug 09-Nov 09	84	0.3314	0.2468	0.4599	0.4212
Nov 09 - Apr 10	122	0.1435	0.1131	1.1123	0.6081
Apr 10 - Jul 10	105	0.2038	0.1762	0.7804	0.7812
Jul 10 - Oct 10	81	0.2055	0.1908	1.2503	2.3209
Oct 10 - Jan 11	87	0.1266	0.1351	1.1058	0.1793
Jan 11- May -11	111	0.1861	0.2529	0.6949	0.4477
May 11 - Sep 11	133	0.1047	0.2181	0.854	1.1106

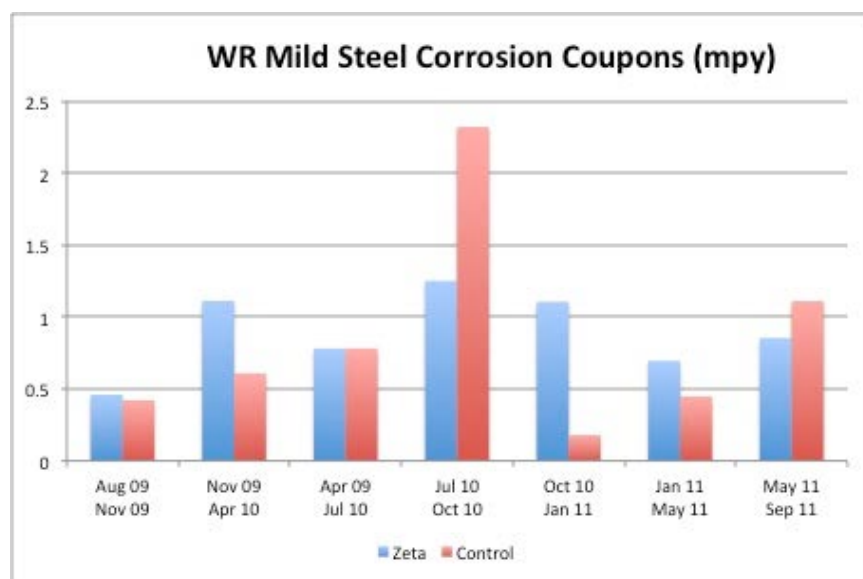
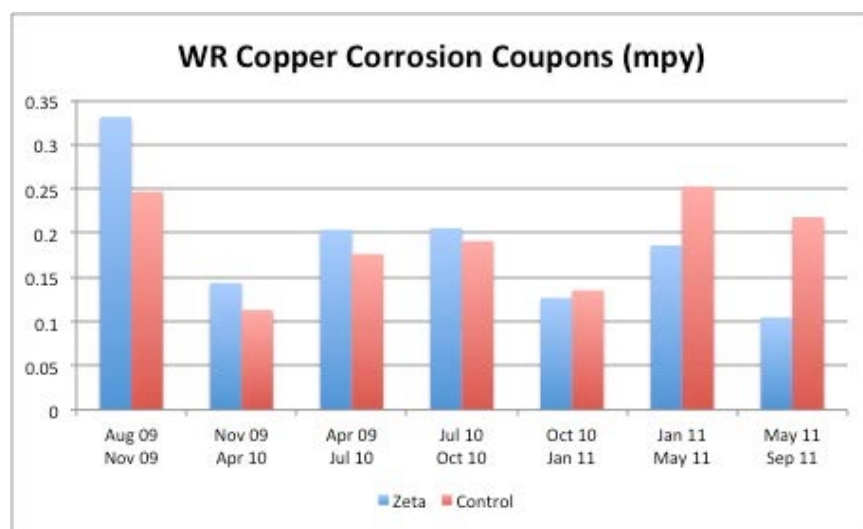
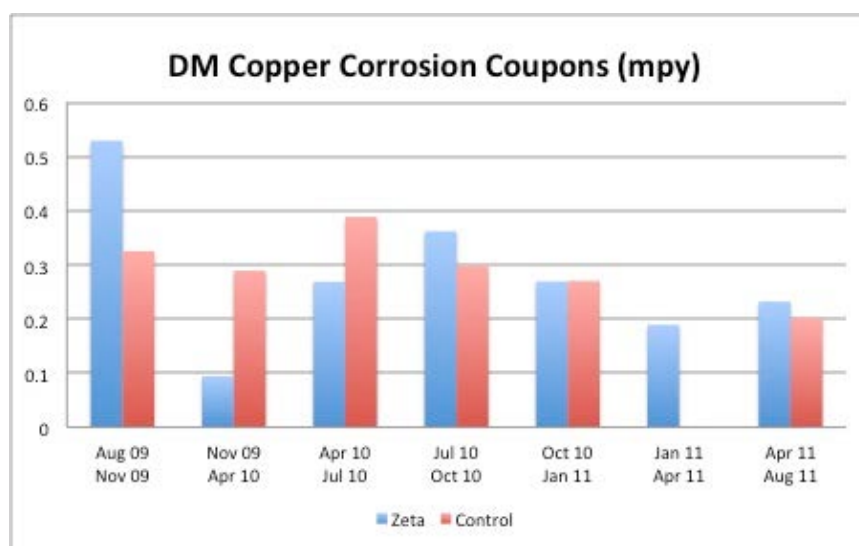


Table A13. Davis-Monthan Corrosion Coupon Results					
		Zeta		Control	
Period	Days Exposed	Galv. S.	Copper	Stainless S.	Copper
Aug 09 - Nov 09	88	2.5978	0.5295	0.094	0.3254
Nov 09 - Apr 10	161	0.6312	0.0945	NA	0.2893
Apr 10 - Jul 10	86	2.2581	0.2688	NA	0.3889
Jul 10 - Oct 10	89	2.667	0.3621	NA	0.2985
Oct 10 - Jan 11	84	1.789	0.2696	0.0547	0.2705
Jan 11 - Apr 11	90	1.0377	0.1893	0.0023*	0.7462*
Apr 11 - Aug 11	143	1.3498	0.2323	0.1032	0.2022
* Dates Exposed Feb 28 through April 5, 2011, total exposure 36 days.					



Water Use

Each cooling tower (with the exception of the WR control) was equipped with a water meter in the MU and the BD lines that connected to the data monitoring system.

Tables A14 through A18 show the water used by each site, and the volumetric cycles of concentration that each tower maintained.

Table A14. Davis-Monthan Monthly Water Use (gal/month)						
	Zeta			Control		
	MU	BD	CC	MU	BD	CC
Aug 09	79,750	41,480	1.9	17,680	3,870	4.6
Sep 09	77,240	15,300	5.0	35,010	6,320	5.5
Oct 09	73,730	12,920	5.7	22,390	4,560	4.9
Nov 09	70,260	9,890	7.1	10,880	2,350	4.6
Dec 09	4,460			2,290	640	3.6
Jan 10	4,670			4,840	910	5.3
Feb 10	7,030	1,310	5.4	3,190	930	3.4
Mar 10	19,680	4,820	4.1	5,260	980	5.4
Apr 10	27,900	6,040	4.6	13,660	3,330	4.1
May 10	44,290	8,140	5.4	37,610	9,630	3.9
Jun 10	60,160	10,350	5.8	38,050	8,990	4.2
Jul 10	82,960	13,110	6.3	43,520	10,980	4.0
Aug 10	66,070	9,120	7.2	33,220	6,400	5.2
Sep 10				30,590	4,490	6.8
Oct 10	28,180	3,680	7.7	18,120	4,280	4.2
Nov 10	31,960	3,030	10.5	8,780	1,510	5.8
Dec 10	35,310	2,360	15.0	7,560	2,140	3.5
Jan 11	64,340			4,230	1040	4.1
Feb11	107,910			1,910	300	6.4
Mar 11	24,580			9,320	1720	5.4
Apr 11	29,550	500	59.1	12,330	160	77.1
May 11	43,050	1,280	33.6	13,820	40	345.5
Jun11	96,150	4,030	23.9	31,220	5480	5.7
Jul 11	84,260	860	98.0	33,910	6490	5.2
Total	1,163,490	148,220	7.8	439,390	87,540	5.0

From Jan 2011 through the end of the project, the makeup float valve in the Zeta unit was improperly set. This allowed water in the unit to be constantly overflowing. A similar situation took place in the control unit between April and May 2011. The overflow pipe is not piped through the blowdown water meter, so this water was only accounted for through the makeup and not the blowdown, resulting in what appear to be very high cycles of concentration.

Table A15. Fort Huachuca Monthly Water Use (gal/month)						
	Zeta			Control		
	MU	BD	CC	MU	BD	CC
Aug 09	266,016	51,405	5.17	311,814	47,854	6.52
Sep 09	544,040	109,050	4.99	682,580	191,430	3.57
Oct 09	322,210	64,510	4.99	225,460	66,220	3.40
Nov 09	308,040	61,930	4.97	272,890	83,980	3.25
Dec 09	210,140	42,030	5.00	180,100	61,610	2.92
Jan 10	168,520	13,980	12.05	162,980	25,910	6.29
Feb 10	173,370	28,210	6.15	170,270	40,950	4.16
Sub Total 1	1,992,336	371,115	5.37	2,006,094	517,954	3.87
Mar 10	300,950	68,910	4.37	228,010	58,550	3.89
Apr 10	470,470	190,170	2.47	278,620	73,120	3.81
May 10	452,280	107,460	4.21	520,690	159,660	3.26
Jun 10	668,210	193,440	3.45	839,460	252,010	3.33
Jul 10	758,180	303,910	2.49	791,850	258,300	3.07
Aug 10	743,430	261,460	2.84	768,460	273,110	2.81
Sep 10	611,640	177,660	3.44	565,390	203,170	2.78
Oct 10	237,950	69,040	3.45	439,150	121,870	3.60
Nov 10	353,260	143,890	2.46	248,100	63,910	3.88
Dec 10	315,280	114,260	2.76	222,990	63,780	3.50
Jan 11	209,870	79,257	2.65	226,550	37,660	6.02
Feb 11	282,750	116,480	2.43	358,880	23,650	15.17
Mar 11	416,460	144,590	2.88	240,950	71,480	3.37
Apr 11	479,290	183,720	2.61	329,330	112,750	2.92
May 11	463,200	202,790	2.28	450,190	137,710	3.27
Jun 11	697,790	234,640	2.97	930,450	381,610	2.44
Jul 11	712,750	214,490	3.32	834,874	350,433	2.38
Aug 11	615,930	261,860	2.35	747,563	319,146	2.34
Subtotal 2	8,789,690	3,068,027	2.86	9,021,508	2,961,918	3.05
TOTAL	10,782,027	3,439,142	3.14	11,027,602	3,479,872	3.17

Fort Huachuca water use is split into two periods: Aug 2009 - Feb 2010 and Mar 2010 - Aug 2011. The Zeta cooling tower operated without chemicals at higher cycles during the first period. During the second period, the cooling tower ran as a hybrid chemical/Zeta system, BD control was changed from the Zeta controller to the chemical feed controller, and cycles of concentration were reduced under the chemical vendor management.

Table A16. Fort Irwin Monthly Water Use (gal/month)						
	Zeta			Control		
	MU	BD	CC	MU	BD	CC
Aug 09	182,700	35,780	5.11	92,900	2,660	34.92
Sep 09	292,300	73,840	3.96	263,000	31,390	8.38
Oct 09	135,600	67,460	2.01	342,200	283,170	1.21
Nov 09	23,100	5,660	4.08	80,800	72,990	1.11
Dec 09	0	0		0		
Jan 10	0	0		0		
Feb 10	0	0		0		
Mar 10	0	0		0		
Apr 10	0	0		0		
May 10	48,500	6,460	7.51	166,200	83,030	2.00
Jun 10	269,700	195,250	1.38	551,900	425,980	1.30
Jul 10	267,100	185,380	1.44	486,300	508,720	0.96
Aug 10	113,900	53,590	2.13	521,500	505,860	1.03
Sep 10	198,100	103,630	1.91	489,400	439,780	1.11
Oct 10	136,500	56,440	2.42	187,900	141,340	1.33
Nov 10	101,400	14,190	7.15	12,400	4,420	2.81
Dec 10	9,900	50	198.00	116,800		
Jan 11	0	0		0		
Feb 11	0	0		0		
Mar 11	0	0		0		
Apr 11	0	0		0		
May 11	158,700	83,250	1.91	37,600		
Jun 11	332,400	110,960	3.00	142,600	8,900	16.02
Jul 11	417,600	139,660	2.99	214,900	26,680	8.05
Aug 11	297,400	99,280	3.00			
TOTAL	2,984,900	1,230,880	2.43	3,706,400	2,534,920	1.46

Table A17. Warner Robins Monthly & Cumulative Water Use (gal)						
	Zeta			Control (Cumulative Use)		
	MU	BD	CC	MU	BD	CC
Sep 09	296,100	18,340	16.15			
Oct 09	390,500	25,970	15.04			
Nov 09	0	0				
Dec 09	0	0		570,000	8,100	70.37
Jan 10	0	0				
Feb 10	0	0				
Mar 10	0	0				
Apr 10	107,800	2,910	37.04	2,915,000	513,000	5.68
May 10	1,244,500	137,610	9.04	4,208,000	825,000	5.10
Jun 10	1,372,700	165,720	8.28			
Jul 10	1,369,400	84,920	16.13	6,298,000	1,183,700	5.32
Aug 10	1,311,700	198,130	6.62	6,926,000	1,332,100	5.20
Sep 10	1,201,200	184,180	6.52	7,574,000	1,477,450	5.13
Oct 10	465,200	35,760	13.01	8,222,000	1,622,800	5.07
Nov 10	114,500	20		8,267,000	1,640,200	5.04
Dec 10	166,100	0				
Jan 11	0	0		9,539,000	1,815,000	5.26
Feb 11	0	0				
Mar 11	423,300	23,300	18.17			
Apr 11	1,257,400	55,600	22.62			
May 11	1,286,300	69,720	18.45	12,333,000	1,877,900	6.57
Jun 11	1,397,400	80,020	17.46	13,046,000	1,877,800	6.95
Jul 11	1,597,487	89,920	17.77			
Aug 11	1,374,300	91,580	15.01			
TOTAL	15,375,887	1,263,700	12.17	13,046,000	1,877,800	6.95

Water savings calculations

Davis-Monthan Bldg 263 (Zeta)

Table A18. Davis-Monthan Bldg. 263 (Zeta): Estimated Water Savings Aug 09 - Oct 10							
Month	Actual Operating Conditions CC	Evap. (gal)	Estimated Use @ 3.4 CC		Estimated Savings		
			MU (gal)	BD (gal)	MU & BD (gal)	MU (%)	BD (%)
Aug 09	1.9	38,270	54,216	15,946	(25,534)		
Sep 09	5.0	61,940	87,748	25,808	10,508	12%	41%
Oct 09	5.7	60,810	86,148	25,338	12,418	14%	49%
Nov 09	7.1	60,370	85,524	25,154	15,264	18%	61%
Dec 09							
Jan 10			Evap. Condenser Not in Use				
Feb 10	5.4	5,720	8,103	2,383	1,073	13%	45%
Mar 10	4.1	14,860	21,052	6,192	1,372	7%	22%
Apr 10	4.6	21,860	30,968	9,108	3,068	10%	34%
May 10	5.4	36,150	51,213	15,063	6,923	14%	46%
Jun 10	5.8	49,810	70,564	20,754	10,404	15%	50%
Jul 10	6.3	69,850	98,954	29,104	15,994	16%	55%
Aug 10	7.2	56,950	80,679	23,729	14,609	18%	62%
Sep 10	6.5	58,870	83,399	24,529	13,669	16%	56%
Oct 10	7.7	24,500	34,708	10,208	6,528	19%	64%
Estimated Makeup & Blowdown			793,277	233,317	86,297	11%	37%
Makeup & Blowdown Metered			706,980	147,020			

Fort Huachuca SCP (Zeta)

Table A19a. Fort Huachuca SCP (Zeta): Estimated Water Savings Aug 09 – Feb 10							
Month	Operating Conditions		Estimated Use @ 3.0 CC		Estimated Savings		
	CC	Evap. (gal)	MU (gal)	BD (gal)	MU & BD (gal)	MU (%)	BD (%)
Aug 09	5.2	214,611	321,917	107,306	55,901	17%	52%
Sep 09	5.0	434,990	652,485	217,495	108,445	17%	50%
Oct 09	5.0	257,700	386,550	128,850	64,340	17%	50%
Nov 09	5.0	246,110	369,165	123,055	61,125	17%	50%
Dec 09	5.0	168,110	252,165	84,055	42,025	17%	50%
Jan 10	12.1	154,540	231,810	77,270	63,290	27%	82%
Feb 10	6.1	145,160	217,740	72,580	44,370	20%	61%
Estimated Total		1,621,221	2,431,832	810,611	439,496	18%	54%

Table A19b. Fort Huachuca SCP (Zeta): Estimated Unrealized Water Savings Mar 10 - Aug 11

Month	Operating Conditions		Estimated Use @ 5.0 Cycles		Estimated Unrealized Savings		
	CC	Evap. (gal.)	MU (gal.)	BD (gal.)	MU & BD (gal.)	MU (%)	BD (%)
Mar 10	4.4	232,040	290,050	58,010	10,900	4%	19%
Apr 10	2.5	280,300	350,375	70,075	120,095	34%	171%
May 10	4.2	344,820	431,025	86,205	21,255	5%	25%
Jun 10	3.5	474,770	593,463	118,693	74,747	13%	63%
Jul 10	2.5	454,270	567,837	113,567	190,343	34%	168%
Aug 10	2.8	481,970	602,463	120,493	140,968	23%	117%
Sep 10	3.4	433,980	542,475	108,495	69,165	13%	64%
Oct 10	3.4	168,910	211,137	42,227	26,813	13%	63%
Nov 10	2.5	209,370	261,713	52,343	91,548	35%	175%
Dec 10	2.8	201,020	251,275	50,255	64,005	25%	127%
Jan 11	2.6	130,613	163,267	32,653	46,603	29%	143%
Feb 11	2.4	166,270	207,838	41,568	74,912	36%	180%
Mar 11	2.9	271,870	339,838	67,968	76,622	23%	113%
Apr 11	2.6	295,570	369,463	73,893	109,827	30%	149%
May 11	2.3	260,410	325,513	65,103	137,688	42%	211%
Jun 11	3.0	463,150	578,938	115,788	118,853	21%	103%
Jul 11	3.3	498,260	622,825	124,565	89,925	14%	72%
Aug 11	2.4	354,070	442,588	88,518	173,343	39%	196%
Estimated Total		5,721,664	7,152,080	1,430,416	1,637,611	23%	114%
Metered Total		5,721,664	8,789,690	3,068,027			

Fort Irwin, Bldg 263 (Zeta)

Table A20. Fort Irwin Bldg. 263 (Zeta): Estimated Water Savings							
Month	Operating Conditions		Estimated Use @ 1.5 CC		Estimated Savings		
	CC	Evap. (gal.)	MU (gal.)	BD (gal.)	MU & BD (gal.)	MU (%)	BD (%)
Aug 09	5.1	146,920	440,760	293,840	258,060	59%	88%
Sep 09	4.0	218,460	655,380	436,920	363,080	55%	83%
Oct 09	2.0	68,140	204,420	136,280	68,820	34%	50%
Nov 09	4.1	17,440	52,320	34,880	29,220	56%	84%
Dec 09-Apr 10	CT out of operation during Winter Mode						
May 10	7.5	42,040	126,120	84,080	77,620	62%	92%
Jun 10	1.4	74,450	223,350	148,900	(46,350)	-21%	-31%
Jul 10	1.4	81,720	245,160	163,440	(21,940)	-9%	-13%
Aug 10	2.1	60,310	180,930	120,620	67,030	37%	56%
Sep 10	1.9	94,470	283,410	188,940	85,310	30%	45%
Oct 10	2.4	80,060	240,180	160,120	103,680	43%	65%
Nov 10	7.1	87,210	261,630	174,420	160,230	61%	92%
Dec 10-Apr 11	CT out of operation during Winter Mode						
May 11	1.9	75,450	226,350	150,900	67,650	30%	45%
Jun 11	3.0	221,440	664,320	442,880	331,920	50%	75%
Jul 11	3.0	277,940	833,820	555,880	416,220	50%	75%
Aug 11	3.0	198,120	594,360	396,240	296,960	50%	75%
Estimated Total		1,744,170	5,232,510	3,488,340	2,247,610	43%	64%
Metered Total		1,744,170	2,984,900	1,230,880			

Warner Robins, Chiller #2 (Zeta)

Table A21. Warner Robins CT #2 (Zeta): Estimated Water Savings							
Month	Operating Conditions		Estimated Use @6 CC		Estimated Savings		
	CC	Evap. (gal.)	MU (gal.)	BD (gal.)	MU & BD (gal.)	MU (%)	BD (%)
Sep 09	16.1	277,760	324,052	46,292	27,952	9%	60%
Oct 09	15.0	364,530	425,284	60,754	34,784	8%	57%
Nov 09 - Apr 10							
Tower Down During Winter Period							
May 10	9.0	1,106,890	1,291,371	184,481	46,871	4%	25%
Jun 10	8.3	1,206,980	1,408,142	201,162	35,442	3%	18%
Jul 10	16.1	1,284,480	1,498,559	214,079	129,159	9%	60%
Aug 10	6.6	1,113,570	1,299,164	185,594	(12,536)	-1%	-7%
Sep 10	6.5	1,017,020	1,186,522	169,502	(14,678)	-1%	-9%
Oct 10	13.0	429,440	501,012	71,572	35,812	7%	50%
Nov 10 - Feb 11							
Tower Down During Winter Period							
Mar 11	18.2	400,000	466,666	66,666	43,366	9%	65%
Apr 11	22.6	1,201,800	1,402,099	200,299	144,699	10%	72%
May 11	18.4	1,216,580	1,419,342	202,762	133,042	9%	66%
Jun 11	17.5	1,317,380	1,536,942	219,562	139,542	9%	64%
Jul 11	17.8	1,507,567	1,758,827	251,260	161,340	9%	64%
Aug 11	15.0	1,282,720	1,496,506	213,786	122,206	8%	57%
Estimated Total		13,726,717	16,014,489	2,287,772	1,027,002	6%	45%
Metered Total		15,375,887	1,263,700				

Evaporative cooler data

Table A22 contains information collected at the two Fort Huachuca evaporative cooler locations.

Table A22. Fort Huachuca Evaporative Cooler Pad Data			
Run 1	Zeta	Control	
Date in		9/24/09	
Date Out		11/12/09	
Days Exposed		49	
Pad Area m2 (ft2)	0.3 (10.59)	0.19 (6.64)	
# of Pads Used	1	1	
Weight In g (oz)	505 (17.8)	315 (11.1)	
Weight Out g (oz)	621 (21.9)	320 (11.3)	
Weight Gain g (oz)	116 (4.1)	6 (0.2)	
Weight Gain/Area g/m2 (oz./ft2)	118.2 (0.387)	9.18 (0.0301)	
Run 2	Zeta	Control	
Date in		4/20/10	
Date Out		7/22/10	
Days Exposed		93	
Pad Area m2 (ft2)	0.3 (10.59)	0.19 (6.64)	
# of Pads Used	1	1	
Weight In g (oz)	515 (18.10)	303 (10.7)	
Weight Out g (oz)	1,262 (44.5)	581 (20.5)	
Weight Gain g (oz)	748 (26.4)	278 (9.8)	
Weight Gain/Area g/m2 (oz./ft2)	761.09 (2.494)	450.11 (1.475)	
Run 3	Zeta	Control	
Date in		5/2/11	
Date Out		10/17/11	
Days Exposed		168	
Pad Area m2 (ft2)	0.3 (10.59)	0.19 (6.64)	
# of Pads Used	3	6	
Total Pad Area m2 (ft2)	2.95 (31.755)	3.703 (39.864)	
Water Used m3 (gal.)	38.102 (10,080)	37.42 (9,900)	
Weight In g (oz)	1,533.7 (54.1)	2,078.01 (73.3)	
	6,063.96	8,952.77	
Weight Out g (oz)	(213.9)	(315.8)	
	4,530.25	6,874.75	
Weight Gain g (oz)	(159.8)	(242.5)	
Weight Gain/Area g/m2 (oz./ft2)	1,535.6 (5.032)	1,856.3 (6.083)	
d(wt.)/(Area*Volume) g/(m2.m3) / [oz./ft2.gal)]	40.30 (0.0005)	49.6 (0.001)	

Table A23 contains the evaporative cooler pad data from Fort Irwin

Table A23. Fort Irwin Evaporative Cooler Pad Data						
RUN 1						
Date in	9/18/09					
Date Out	11/9/09					
Days Exposed	52					
Pad Area m2 (ft2)	0.97 (10.41)					
# of Pads Used	1 Per Cooler, Three Coolers per Building					
	Zeta Coolers			Control Coolers		
	North	Central	South	North	Central	South
Weight In g (oz)	521.63 (18.4)		518.79 (18.3)		515.96 (18.2)	544.31 (19.2)
Weight Out g (oz)	1,077.28 (38)	Out of Order	1,196.35 (42.2)	Out of Order	726.16 (25.65)	1,461.41 (51.55)
Weight Gain g (oz)	555.65 (19.6)		677.55 (23.9)		211.2 (7.45)	
Weight Gain/Area g/m2 (oz/ft2)	574.67 (1.88)		700.75 (2.29)		218.43 (0.715)	948.5 (3.11)
RUN 2						
Date in	5/12/10					
Date Out	7/27/10					
Days Exposed	76					
Pad Area m2 (ft2)	0.97 (10.41)					
# of Pads Used	1 Per Cooler, Three Coolers per Building					
	Zeta Coolers			Control Coolers		
	North	Central	South	North	Central	South
Weight In g (oz)	527.30 (18.6)		524.46 (18.5)		521.63 (18.4)	538.64 (19.0)
Weight Out g (oz)	1,706.64 (60.2)	Out of Order	1,119.8 (39.5)	Out of Order	983.73 (16.3)	3,855.53 (136.0)
Weight Gain g (oz)	1,179.34 (41.6)		595.34 (21)		462.1 (16.3)	3,316.89 (117)
Weight Gain/Area g/m2 (oz/ft2)	1,219.71 (3.99)		615.72 (2.01)		477.91 (1.56)	3,430.43 (11.24)

Appendix B: Borescope Results

Introduction

Borescope inspections were performed on the Zeta and Control chillers at each location on the following dates:

- Fort Irwin: Feb. 1st & 2nd 2010, Jan 6th 2011, and Dec 12th 2011.
- Fort Huachuca: Feb 11th, 2010, Jan 10th 2011, and Nov 18th 2011.
- Warner Robins: Feb. 8th & 9th, 2010, Jan 13th 2011, and Dec 14th & 15th, 2011.

Initial borescope inspections were performed to set a baseline that established the conditions of the chiller tubes at the beginning of the project. Subsequent inspections compared the conditions of the tubes relative to scaling throughout the project.

At each site, representative numbers of tubes in each chiller were selected to be the “reference tubes”. The tubes selected were recorded, and a video file was generated for each tube. Subsequent borescopes inspected the same tubes and videos files were generated so that they could be compared over time. At each site, additional tubes were randomly inspected. Still images were made, noting the tube and the location within the tube where any anomaly was found so that future inspections of the same location could be made.

Tube Labeling.

In order to identify the tubes inspected at each site, the following labeling system was applied:

Roman numeral, (Arabic numeral)

Where:

Roman numeral indicates the row number (counting top to bottom) in which the tube is located. A negative Roman numeral would indicate the row number counting from the bottom up.

Arabic numeral indicates the tube number (positive number counting from the left).

Example: V (4) is the fourth tube from the left in the fifth row of tubes.

Fort Irwin

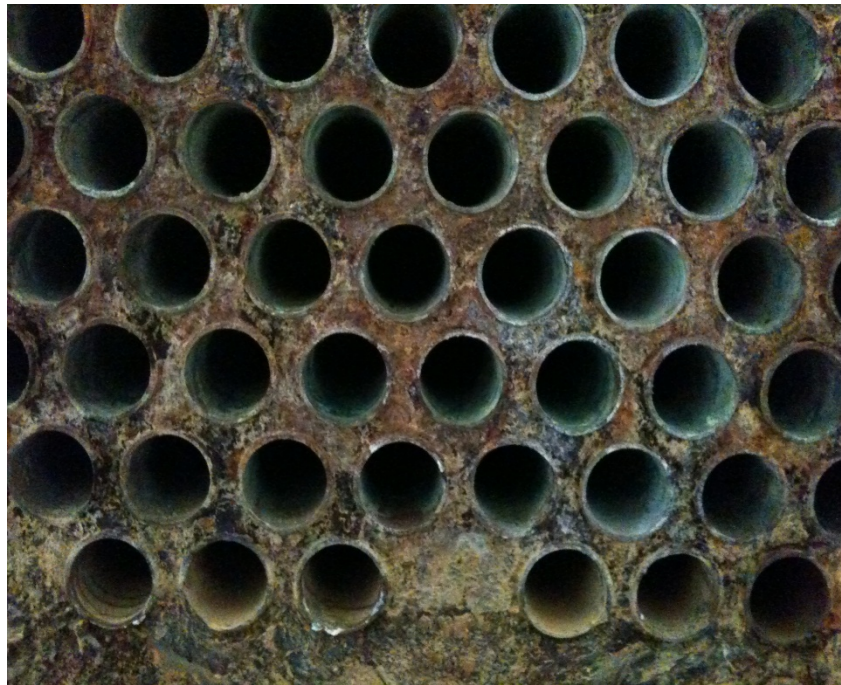
BLDG 263 (Zeta)

Tubes Inspected:
I (3)
III (10)
V (1)
V (15)
VI (3)
VI (12)
VII (11)
IX (5)
XI (1)
XI (6)

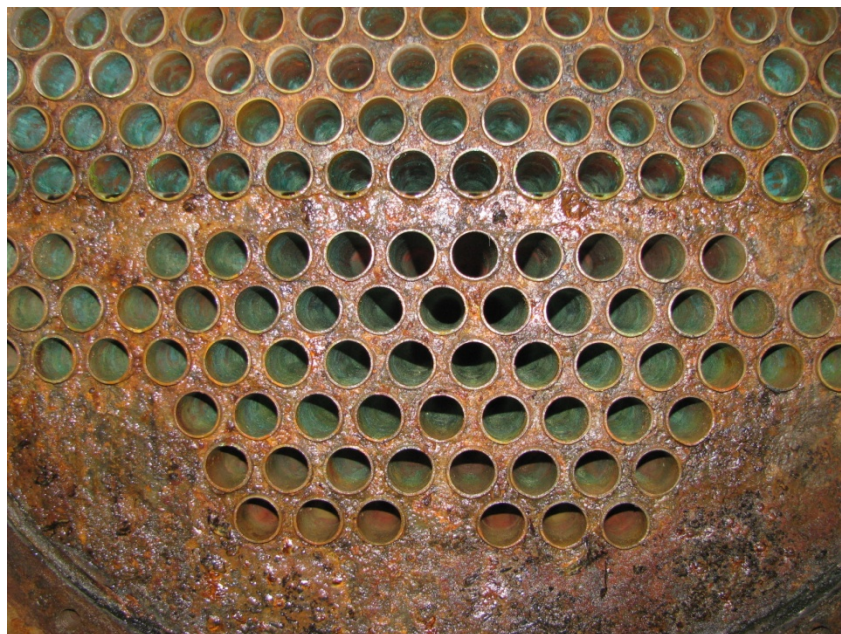


Tubes showed some improvement in condition over the period of the Dem/Val. The following pictures show the condition of the tube sheet during the three inspections. During the Feb 2010 inspection, a light layer of scale could be seen on the surface of the tubes in the lowest row. The same tubes showed no visible scale deposits by the Jan 2011 inspection.

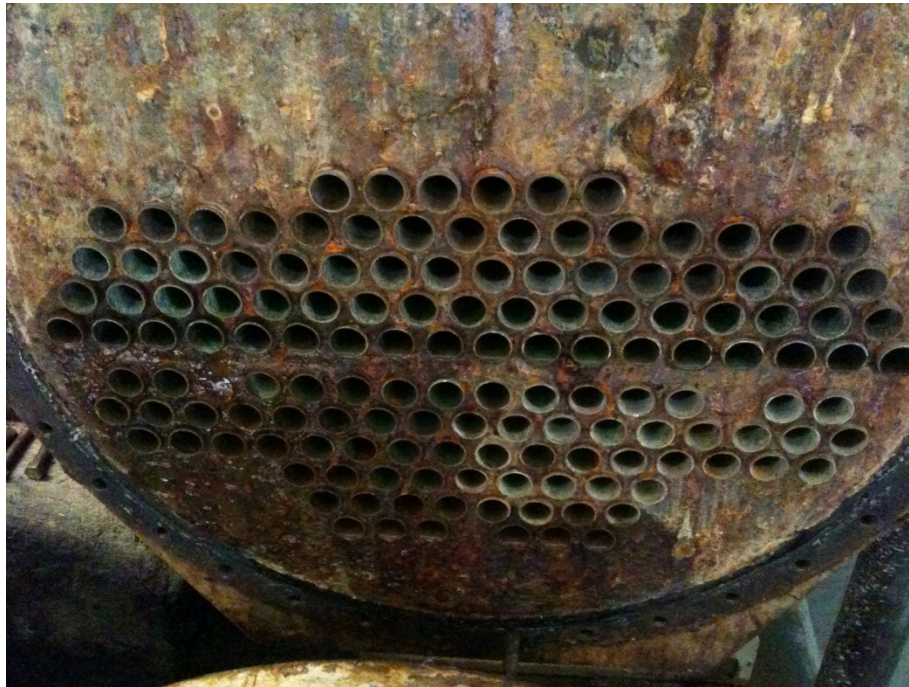
Video of the tubes shows the tube surfaces remained unchanged over the two-year project period.



Feb 1st, 2010: Baseline inspection at Fort Irwin, Bldg 263 (Zeta) condenser tube sheet. Notice scale layer on surface of the 2nd and 4th tube of the lowest row.



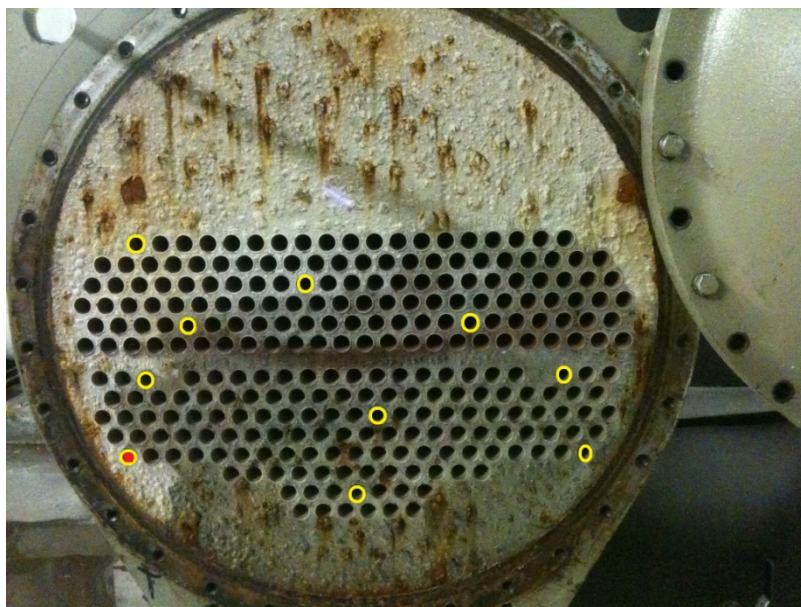
January 6, 2011: Fort Irwin, Bldg 263 (Zeta) condenser tube sheet. The layer of scale previously seen on the 2nd & 4th tubes of the lower row is no longer present. No cleaning (mechanical or chemical) took place between the two inspections.



December 12, 2011: Fort Irwin Bldg 263 (Zeta) condenser tube sheet showing no visible signs of scale on any of the tubes or the tube sheet after operating for two years without any chemical treatment.

BLDG 273 (Control)

Tubes Inspected
I (1)
III (10)
V (5)
V (17)
VII (3)
VII (19)
IX (13)
XI (1)
XI (21)
XIV (4)

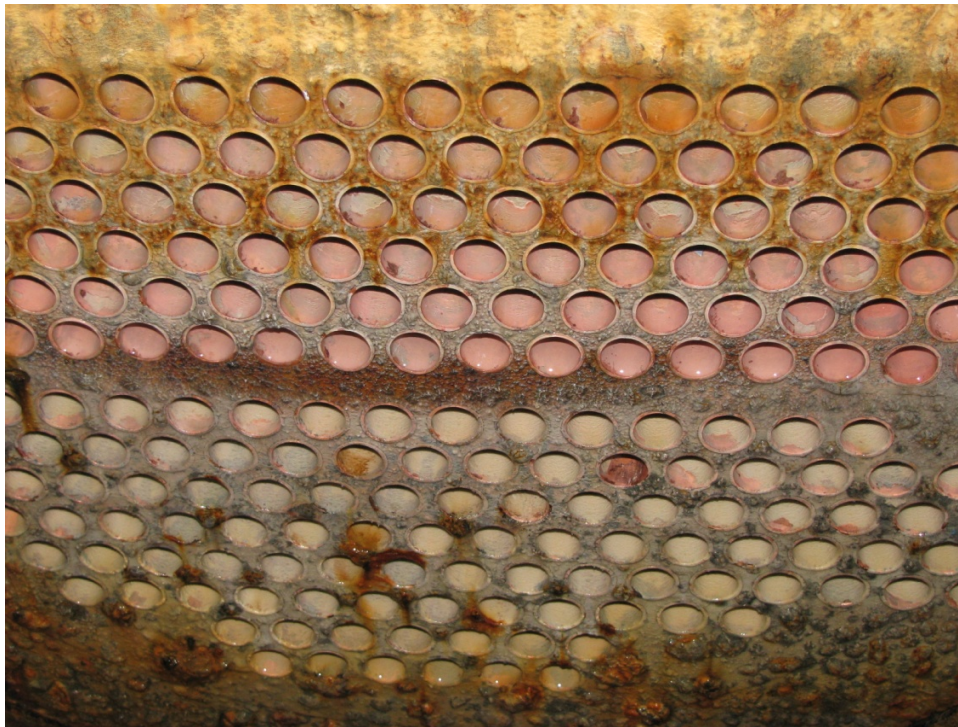


Upon the initial inspection the tubes in the condenser showed a visible layer of scale on all tube surfaces, indicating scaling of the tubes. Over the course of the evaluation, the condition of the tubes worsened. Scale on some sections of tubes was scraped off to determine whether new scale would form on the tubes, or to determine if the scale present during the first inspection was old scale and it was being controlled. In the two following inspections, the cleaned sections of tubes had scaled over.

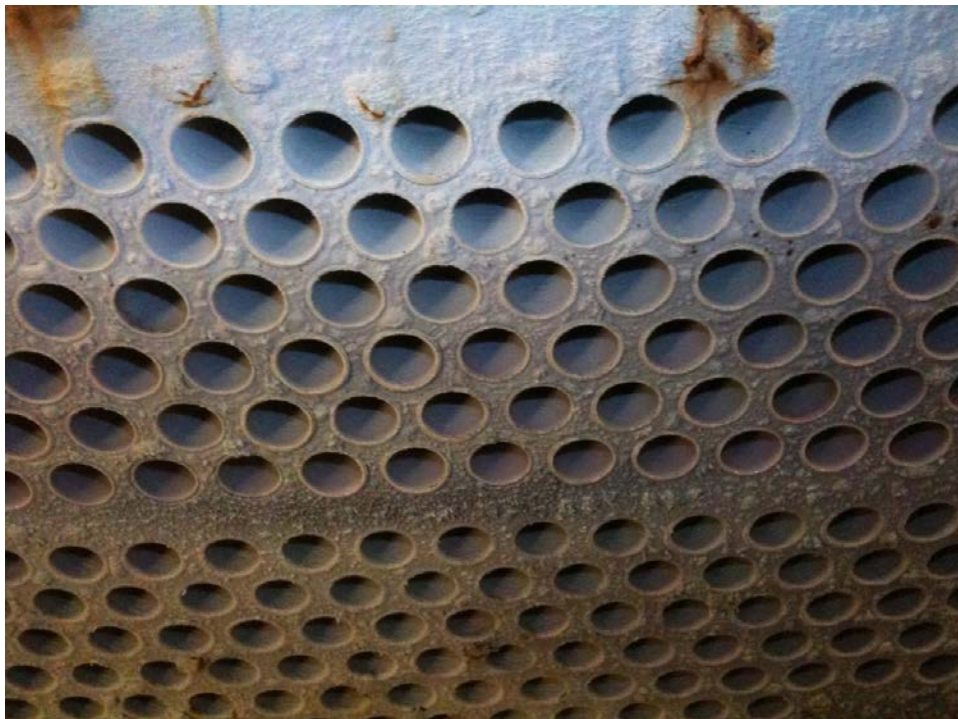
This cooling tower had problems with the chemical delivery system on a couple of occasions between inspections. During these periods the chemical control tower operated with no chemicals and the condenser tubes scaled over. This provides valuable information, for it validates that the Zeta treatment used at Fort Irwin was capable of preventing scale formation on the treated chiller after two years of operation without any chemicals; whereas the control system developed scale while operating at lower cycles of concentration and using the same water during two short periods of time in which chemicals were not fed to the tower.



February 2, 2010: Fort Irwin Bldg 273 (Control) – scale visible on tube surfaces. Thicker layer on bottom tubes (second pass) than on the top half tubes (first pass).



January 6, 2011: Fort Irwin Bldg 273 (Control) – Scale still present on tubes. This picture was taken after the tubes had been brushed clean.



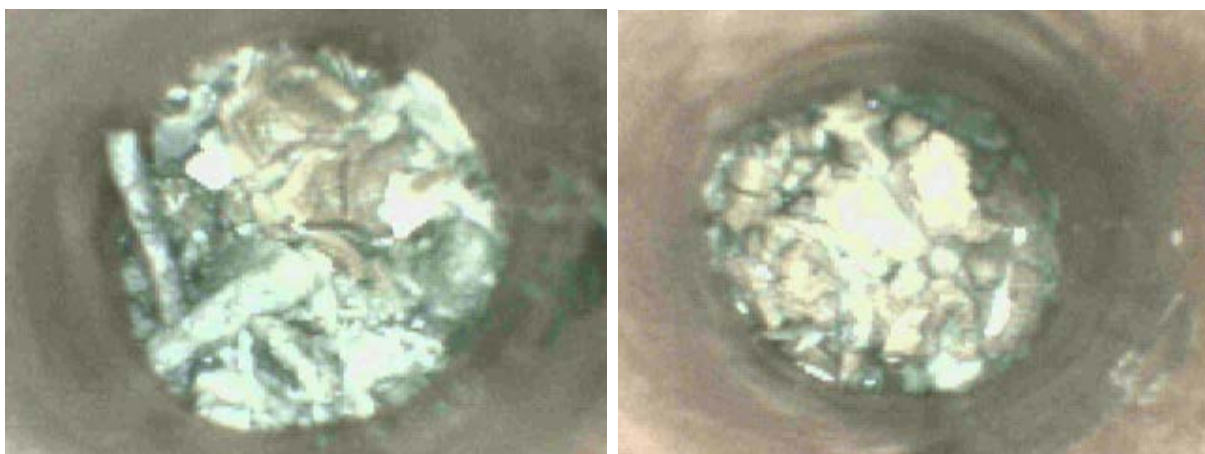
December 12, 2011: Fort Irwin Bldg 273 (Control) – A heavier layer of scale is now seen on all tubes both on the first pass and second pass, as well as on the tube sheet itself.

Fort Huachuca

South Central Plant SCP (Zeta)

On February 11, 2010 an old Carrier chiller was decommissioned and replaced with a new Trane chiller. Until then, the SCP had a 500 RT Trane chiller that had been installed one year prior and had been operating without any chemicals for that period of time. For the previous year, the newer Trane chiller had been used as the lead chiller carrying most of the load for the plant.

When the decommissioned chiller was opened, some tubes showed severe fouling. These were the same tubes that had been identified as being partially blocked during a previous inspection one year earlier. The tubes had not been cleaned as recommended, and the chiller was allowed to operate in that manner. Further inspection showed that only those tubes with debris plugs had severe fouling. This is not an indication of the water treatment program not performing, but rather a maintenance issue of the cooling tower basin. The following pictures show the detail of the plugs formed on the front-end (water in) side of the tubes of the decommissioned chiller.



The next two pictures show the tube sheet's condenser water supply side (left) and condenser water return side (right). As can be seen on the supply side, the tube surfaces prior to the blockage show a clean copper surface. The return side shows the severe fouling on the blocked tube surfaces. This is a result of the no flow zone created in the tube that leads to a high temperature area. This combination permitted scale formation in the affected tubes.

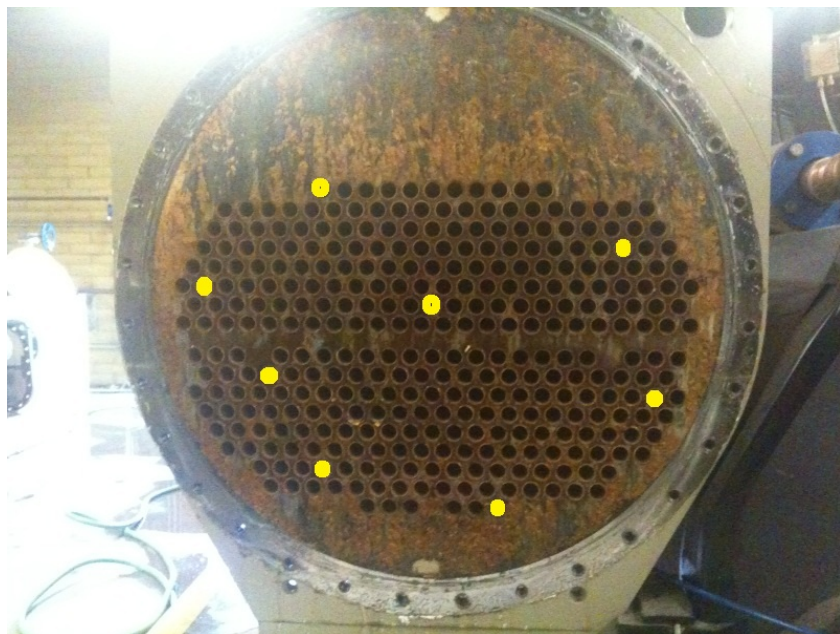


If this had been a result of bulk scale formation, then all the tubes would have shown an even layer of scale.

When the Trane chiller, which had been operating for a year without chemicals, was opened for inspection, no scale was found on any of the tubes inspected.

This became the monitoring unit for the remainder of the project. The tubes inspected were:

Tubes Inspected
I (1)
IV (-3)
VI (2)
VII (12)
II (4)
III (-2)
VII (4)
IX (-1)

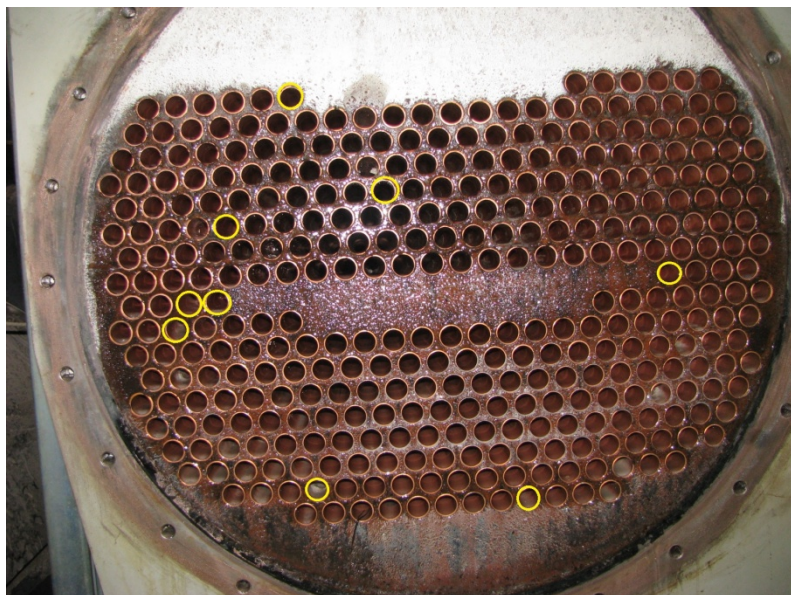


The borescope video files show that no scale formed on any of the tubes during the remainder of the evaluation.

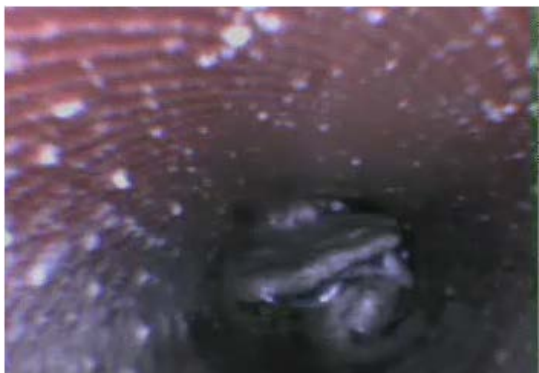
North Central Plant NCP (Control)

Due to base personnel scheduling problems, no borescope inspections were performed in the NCP during February of 2010 (first scheduled inspection). Instead, the first inspection took place in January 2011. The tubes inspected were:

Tubes Inspected
I (6)
V (10)
VI (5)
IX (4)
IX (-4)
-II (4)
-II (4)
-I (-4)
-I (-4)
X (3)
IX (3)

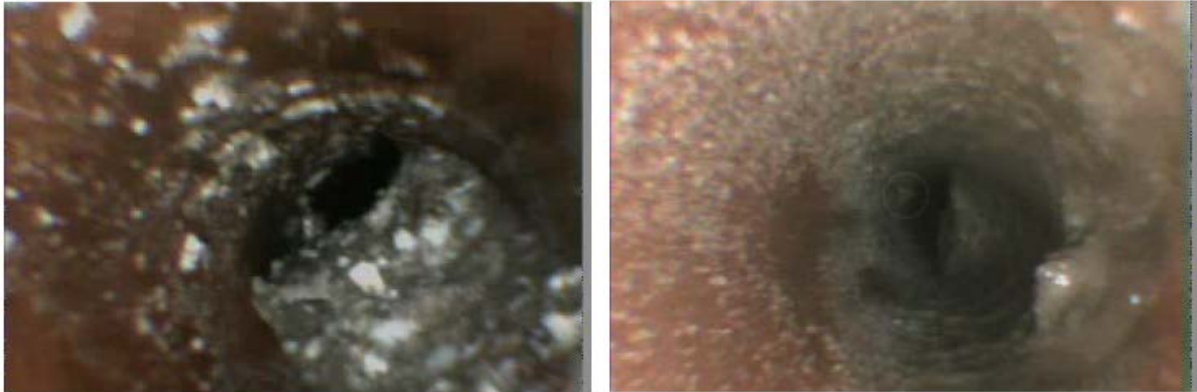


January 10, 2011: Upon opening of the condenser, the first thing that was noticed were several tubes showing debris blockage similar to what had been observed in the decommissioned chiller in the SCP during the Feb 2010 inspection. In general, the non-affected tubes showed no scale deposition, however, some of the affected tubes were starting to show signs of scale buildup. Tubes were cleaned prior to restarting the chiller.

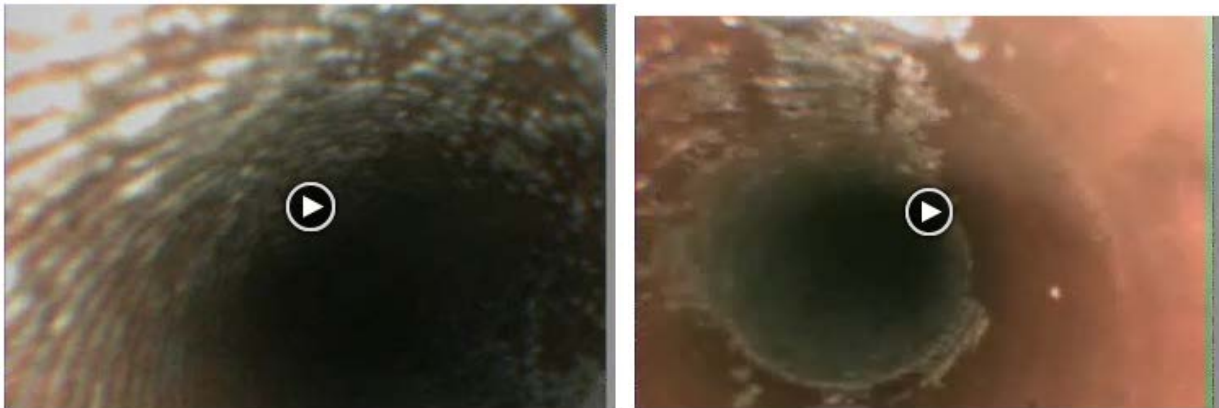


January 10, 2011: Fort Huachuca NCP (Control) debris blockage in some of the tubes.

November 18, 2011: Once again several tubes (different tubes from the previous inspection) showed signs of debris accumulation and blockage.



November 18 2011: Fort Huachuca NCP (Control) debris blockage and sediment accumulation in some of the tubes.



November 18, 2011: Fort Huachuca NCP (Control) frame grabs from video files showing scale starting to form on some of the affected tubes.

Warner Robins

Tubes Inspected

Chiller #2 (Zeta)	Chiller #4 (Control)
I (1)	XII (-1)
I (16)	I (1)
III (14)	I (-1)
V (5)	IV (15)
V (26)	IV (-15)
VII (16)	VIII (5)

Chiller #2 (Zeta)	Chiller #4 (Control)
IX (1)	VIII (-5)
IX (32)	XII (10)
XI (16)	XII (-10)
XII (10)	XVII (1)
XII (20)	-I (5)
XIII (5)	-I (-5)
XIII (26)	-V (1)
XV (17)	-V (-1)
XVII (1)	-VI (15)
XVII (32)	-VI (-15)
XIX (15)	-XIX (1)
XXI (9)	-XIX (-1)
XXI (18)	
XXIII (13)	
XXIV (1)	
XXIV (23)	

Tubes in both chillers showed clean surfaces during all three inspections. This was expected given the low scaling potential of the water at the location. Some cooling tower debris was found in some of the tubes of both chillers during the inspections. In each occasion, the debris was easily pushed out with the tip of the borescope.

Video files were created for each one of the above-mentioned tubes during each one of the three inspections.

Davis-Monthan

Bldg 2301 (Zeta)

This evaporative condenser had been under evaluation since the summer of 2007. When that project had started, the tubes in the condenser had a slight layer of scale buildup on their surfaces. Two tube sections were selected as a scale monitoring “coupon” and were mechanically cleaned of scale and marked using tie wraps. The tube sections were monitored and photographed over time to determine if any new scale was forming.

Over the 4 years in which the evaporative condenser was evaluated, no noticeable amount of scale was formed on the clean tube surfaces as seen in the following pictures:

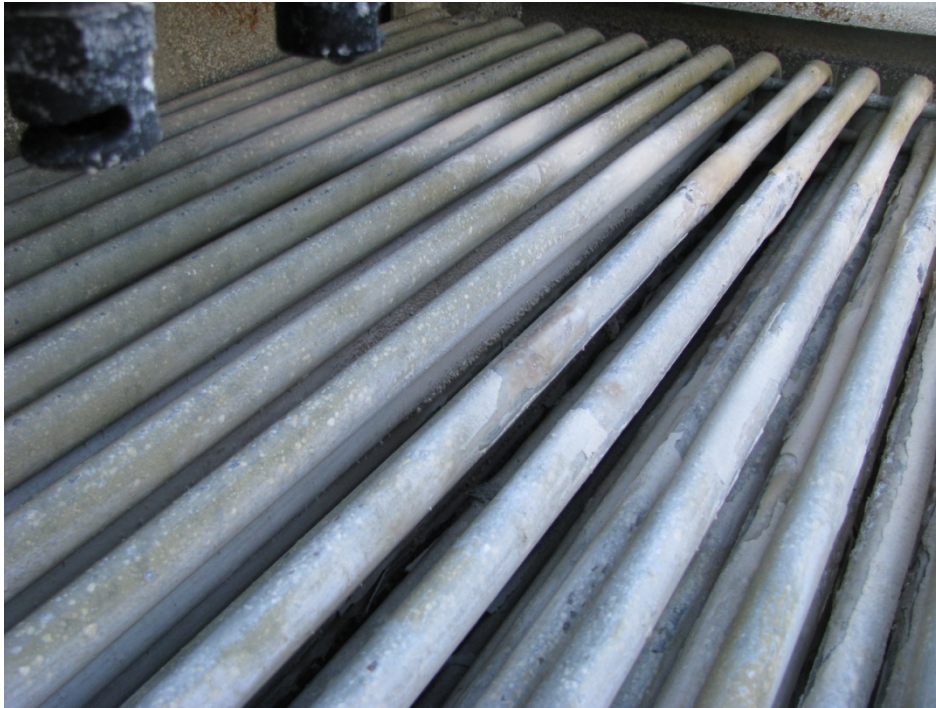


August 17, 2009. December 15, 2009



February 28, 2011

The following pictures show the general condition of the tubes in the evaporative condenser on February 28, 2011. This unit had been operating since the summer of 2007 without the use of any chemicals.



Appendix C: Suggested Implementation Language

The following text is draft language suggested for inclusion in Unified Facilities Guide Specification Section 23 25 00, *Chemical Treatment of Water for Mechanical Systems*, which is the primary DoD reference for specifying mechanical system water treatment practice. The purpose of this addition to UFGS 23 25 00 is to provide guidance for specifying the demonstrated nonchemical, capacitor-based water treatment technology for DoD cooling tower water-treatment systems.

2.6.5 Nonchemical Treatment System for Cooling Tower Water Treatment Systems

NOTE: Nonchemical treatment of cooling tower water has been found to be a viable option for many projects. Significant water and cost savings can be realized depending on the projects cooling systems size, amount of yearly operating time for the system and condition of the make-up water. ERDC-CERL has performed studies and demonstrations of a pulsed electric-field type of nonchemical treatment on cooling systems at a number of U.S military bases. The results are documented in two Technical Reports: ERDC/CERL TR-09-20 (2009), *Demonstration of Electronic Capacitor-Based Water Treatment System for Application at Military Installations* (Alfred D. Beitelman, M. Michael Pitts Jr. PhD, Rodrigo F.V. Romo, and Carolyn B. Pitts); and ERDC/CERL TR-14-15 (2014), *Demonstration of Noncorrosive, Capacitance-Based Water-Treatment Technology for Chilled-Water Cooling Systems* (Alfred D. Beitelman and Michael K. McInerney). The demonstration sites had a wide range of makeup water characteristics and climatic conditions. This technology involves installing high-voltage electrodes into the cooling tower piping to create a strong electrostatic field in the water stream. The ERDC-CERL studies found:

a. By charging the dispersed particles of the cooling tower water, particle deposition and agglomeration onto the heat transfer surfaces is greatly reduced. As a result tower water flushing and refilling was greatly decreased as compared to chemically treated water.

The average annual water costs savings was found to range from approximately \$2,700 to \$20,599 with initial system costs ranging from \$21K to \$32K. The return on investment ranged from 19 to 43 months.

b. Rather than monthly testing of the water's scale and biological content with chemically treated systems the non-chemical system utilized remote wireless monitoring and control. This provided the capability to detect potential corrosion or biological growth problems in a much shorter time as compared to awaiting chemical test results.

c. The flushed water can be used for gray water usage directly after being flushed without having to be filtered.

d. The HVCB system demonstrated as good or improved scale deposit control at all four military base sites

e. Corrosion control - chemical and the non-chemical treatment were equivalent in all four test sites

f. Biological control - the HVCB system was equal to or exceeded the chemically treated systems in controlling bacterial growth

g. All four bases used significantly less water as compared to when chemically treating the tower water

2. The water savings and use of gray water could contribute to LEED points and compliance with ASHRAE 189.1 (Standard for the Design of High-Performance Green Buildings Except for Low-Rise Residential Buildings)

3. While biological control was found to be very good with the HVCB system other non-chemical systems may not provide as good of results as the chemically treated in addressing biological control. This is especially important with the legionella issue. The planner/designer must be wary of manufacturer's claims. An ASHRAE report of April 2010 "Biological Control in Cooling Water Systems Using Non-Chemical Treatment Devices" is a good reference for a comparison of the various non-chemical treatment methods on this issue.

4. Significant water and cost savings can be realized and abundant gray water can be made available for use in utilizing non-chemical treatment systems. The CERL study indicated very good cost and water savings results for the HVCB system. However, whatever non-chemical system is considered the designer/planner

must perform a life cycle cost analysis for their specific project as the smaller systems may not reap the cost saving benefits as compared to the larger systems.

Treat the water to be used in the condenser water systems with a non-chemical treatment system to maintain the conditions recommended by this specification as well as the recommendations from the manufacturers of the condenser and evaporator coils.

2.6.5.1 General Requirements

Provide a high-voltage capacitance-based non-chemical treatment system capable of controlling corrosion, scale, and biological formations. Submit [6] [_____] complete copies, at least 5 weeks prior to the purchase of the water treatment system, of the proposed water treatment plan including a layout; control scheme; a list of existing make-up water chemistry, including the items listed in paragraph Water Analysis; the final treated water control levels; and a description of health, safety and environmental concerns for use of the system, plus any special ventilation requirements. The system shall be initially set manually based on the water analysis of the make-up water. Submit [6] [_____] complete copies of operating and maintenance manuals for the step-by-step water treatment procedures. The manuals shall include testing procedures used in determining water quality.

2.6.5.2 Water Meter

Provide water meters with an electric contacting register and remote accumulative counter. Install the meter within the make-up water line, as indicated.

2.6.5.3 Bleed (Blowdown) Line

Control the flow through the bleed line by a conductivity meter and probe installed to measure the conductivity of the condenser water. The conductivity meter shall have a high and low set point above which the conductivity meter shall open a solenoid valve on the bleed line. The bleed line attachment to the condenser water piping shall be located downstream of the recirculating pumps and upstream of the chemical injection point. The bleed line shall be extended to the nearest drain for continuous discharge. The blowdown shall be controlled based upon the conductivity of the condenser water. All timer set points and blowdown rates shall be determined and set by the water treatment company.

2.6.5.4 Test Kits

One test kit of each type required to determine the water quality as outlined within the operation and maintenance manuals shall be provided.

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